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CPSC 414 Computer Graphics

Advanced Rendering
Final Review

Week 13, Wed 26 Nov 2003

News

- proj 3 demo signup continues
  - record carefully, do **not** miss your demo slot!
- policy clarification
  - cannot use code from web for anything except low-level utilities like file loading (image files, object files)
  - must cite in writeup all web pages that were major inspiration

Schedule: Lab Hours for P3

- Mon Dec 1
  – AG 10-12, AW 12-2
- Tue Dec 2
  – AG 10-12, AW 12-2, TM 2-4
- Wed Dec 3
  – AW 1-2, PZ 2-4
- Thu Dec 4
  – AG 11-1
- Fri Dec 5
  – AG 10-11, PZ 11-1

Schedule: Lectures

- Wed (today)
  - advanced rendering, final review
- Fri
  - (finish review?), other graphics courses
  - evaluations, graphics in movies
    - Pixar shorts

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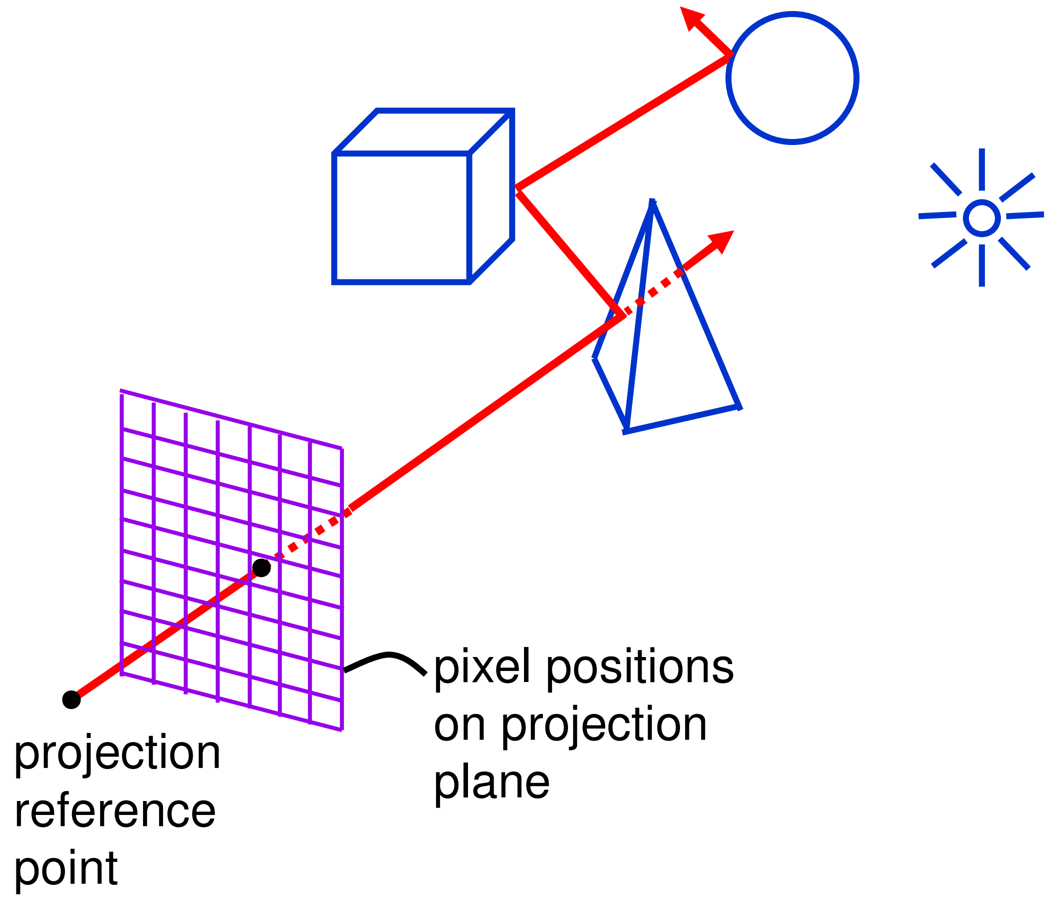
Advanced Rendering

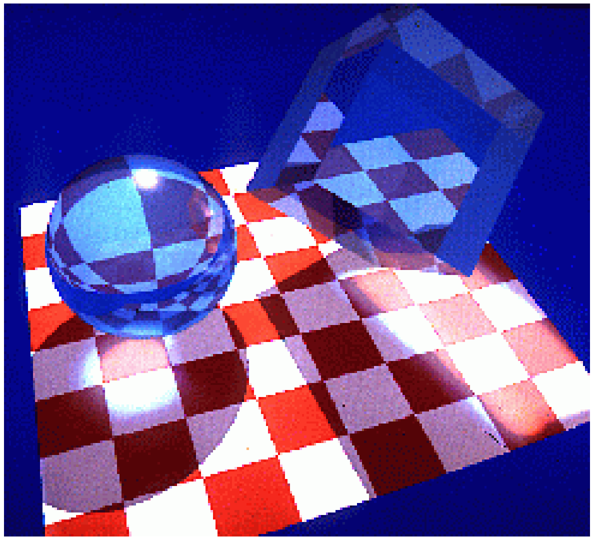
Ray Tracing

- cast a ray from the viewer's eye through each pixel
- compute intersection of ray with objects from scene
- closest intersecting object determines color



Recursive Ray Tracing

- cast ray from intersected object to light sources and determine shadow/lighting conditions
- also spawn secondary rays
  - reflection rays and refraction rays
  - use surface normal as guide (angle of incidence equals angle of reflection)
  - if another object is hit, determine the light it illuminates by recursing through ray tracing
- view-dependent

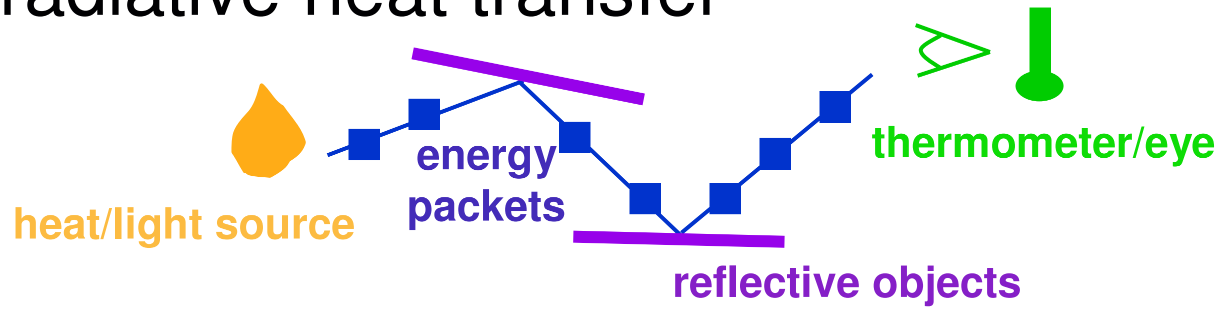


Radiosity

– rate at which energy emitted or reflected by a surface
  - conserve light energy in a volume
  - model light transport until convergence
  - solution captures diffuse-diffuse bouncing of light

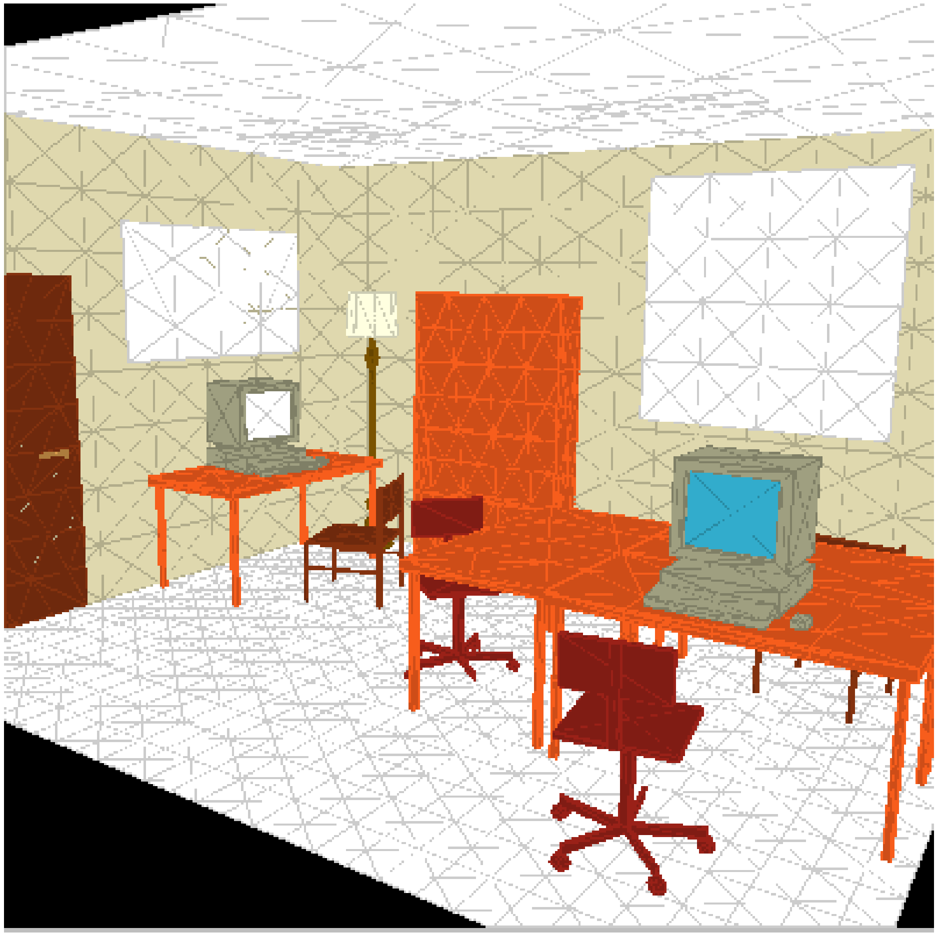


– recall radiative heat transfer



Radiosity

– divide surfaces into small patches
– check “form factor” between all patch pairs (n x n matrix)
– view-independent



Comparison

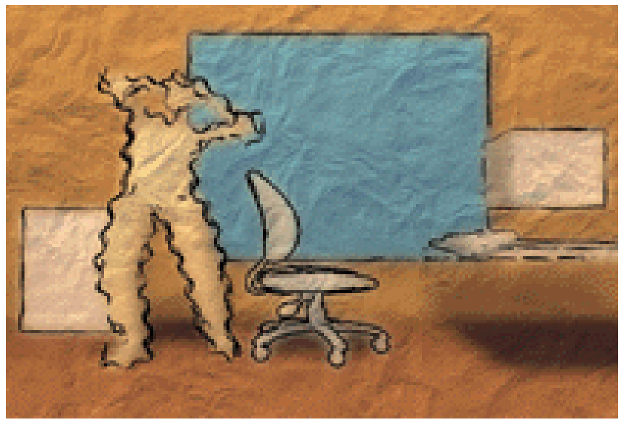
- ray-tracing: great specular, approx diffuse
- radiosity: great diffuse, ignore specular
- advanced hybrids: combine them

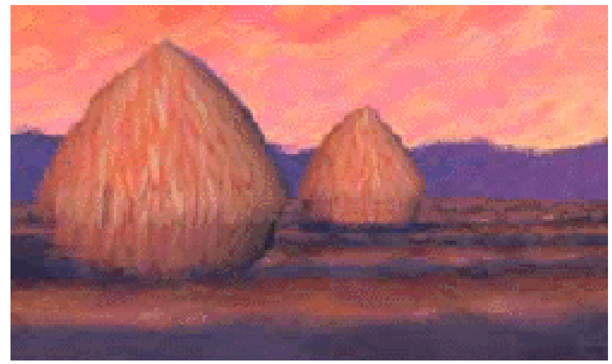
raytraced

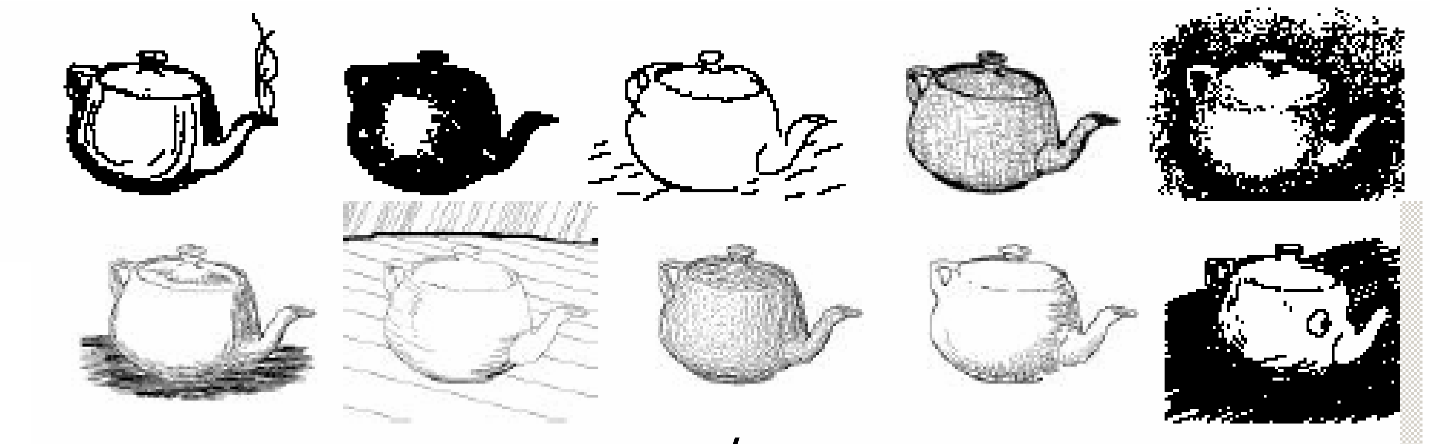
radiosity

Non-Photorealistic Rendering

- look of hand-drawn sketches or paintings







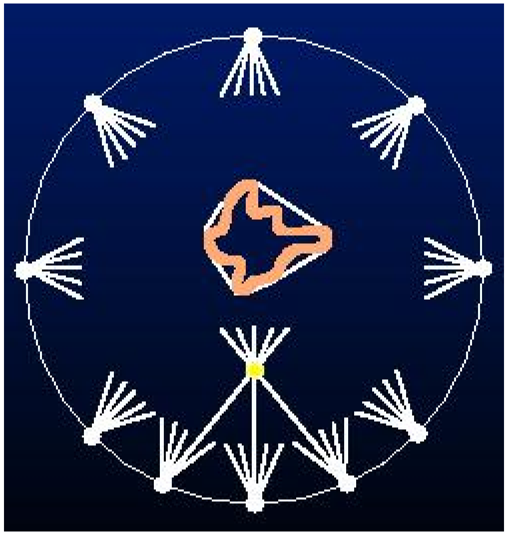
www.red3d.com/cwr/npr/

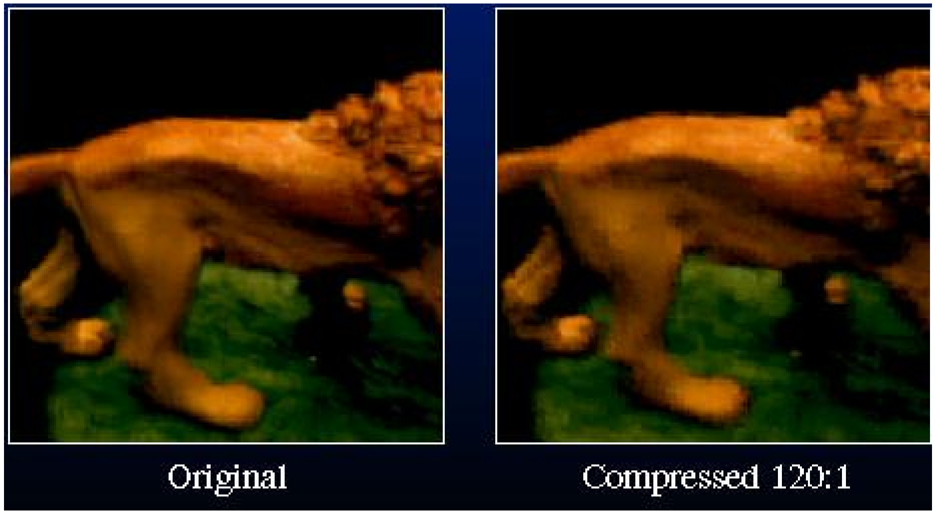
NPRQuake

www.cs.wisc.edu/graphics/Gallery/NPRQuake

Image-Based Rendering

- store and access only pixels
  - no geometry, no light simulation, etc!
  - massive compression possible (120:1)





- display time not tied to scene complexity
  - expensive rendering or real photographs

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Final Review

Logistics

- LSK 200, noon-3pm Tue Dec 9
- policies
  - must have student photo ID face up on desk
    - cannot take exam without photo ID
  - one piece of 8.5”x11” paper allowed
    - both sides handwritten
  - no other books or notes
  - nonprogrammable calculator OK
  - if you finish in last 15 minutes, stay put

Topics Covered

- rendering pipeline
- modelling transformations
- viewing transformations
- projections
- display lists
- picking
- lighting/shading
- rasterization/scan conversion
- sampling/antialiasing
- animation
- texturing
- clipping
- quaternions
- visibility
- color
- visualization
- displays
- procedural approaches
- curves
- advanced rendering

Midterm Covered, Less Emphasis

- rendering pipeline
- modelling transformations
- viewing transformations
- projections
- display lists
- picking
- lighting/shading
- rasterization/scan conversion
- sampling/antialiasing
- animation
- texturing
- clipping
- quaternions
- visibility
- color
- visualization
- displays
- procedural approaches
- curves
- advanced rendering

- for these, look at midterm review notes
  – Week 7 Wed (16 Oct)

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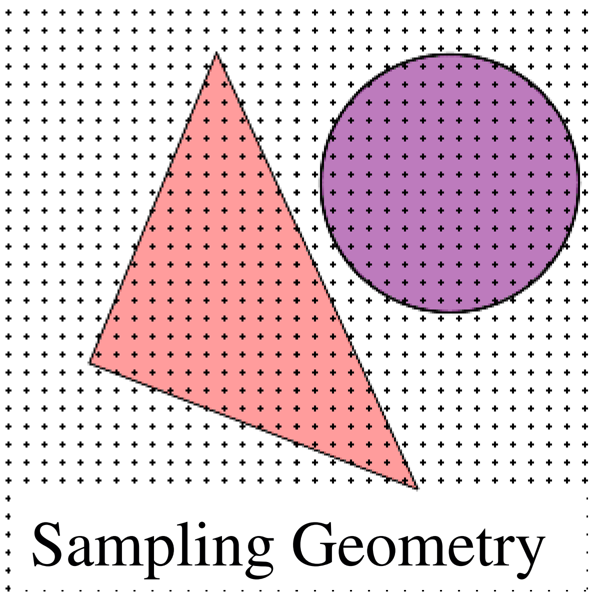
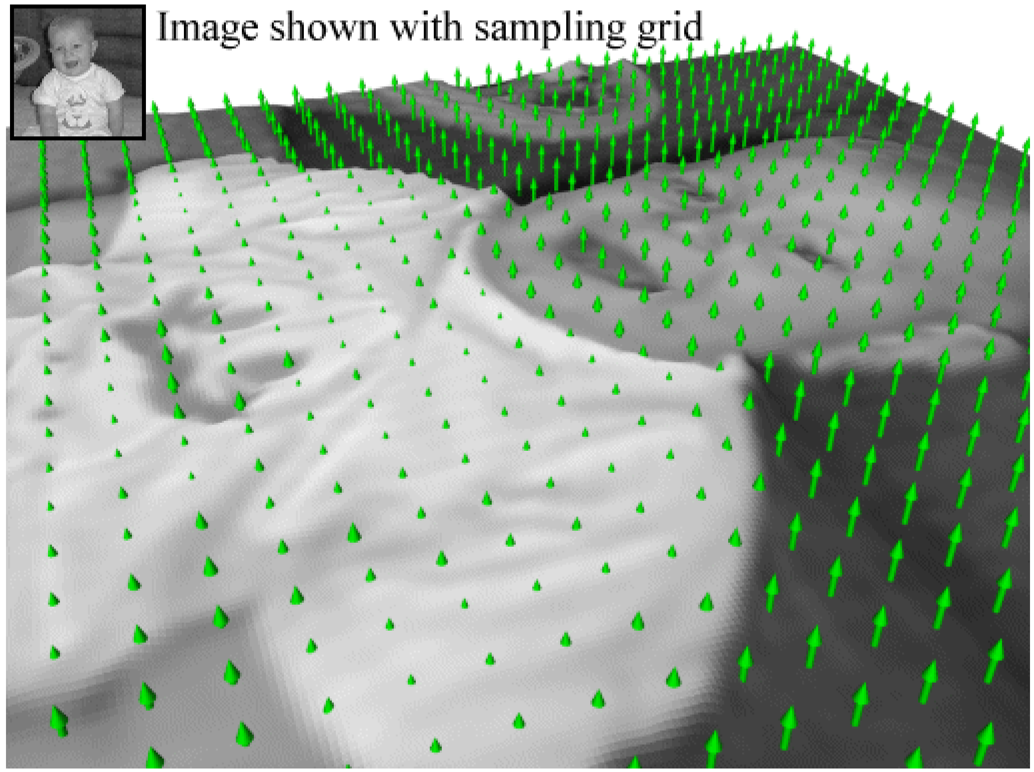
Sampling and Antialiasing

Point Sampling

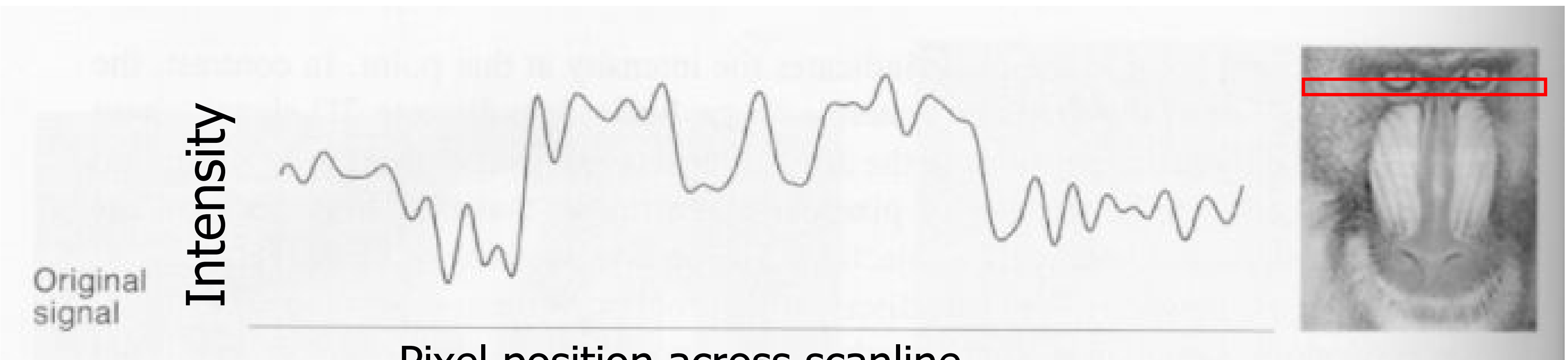
- multiply sample grid by image intensity to obtain a discrete set of points, or samples.





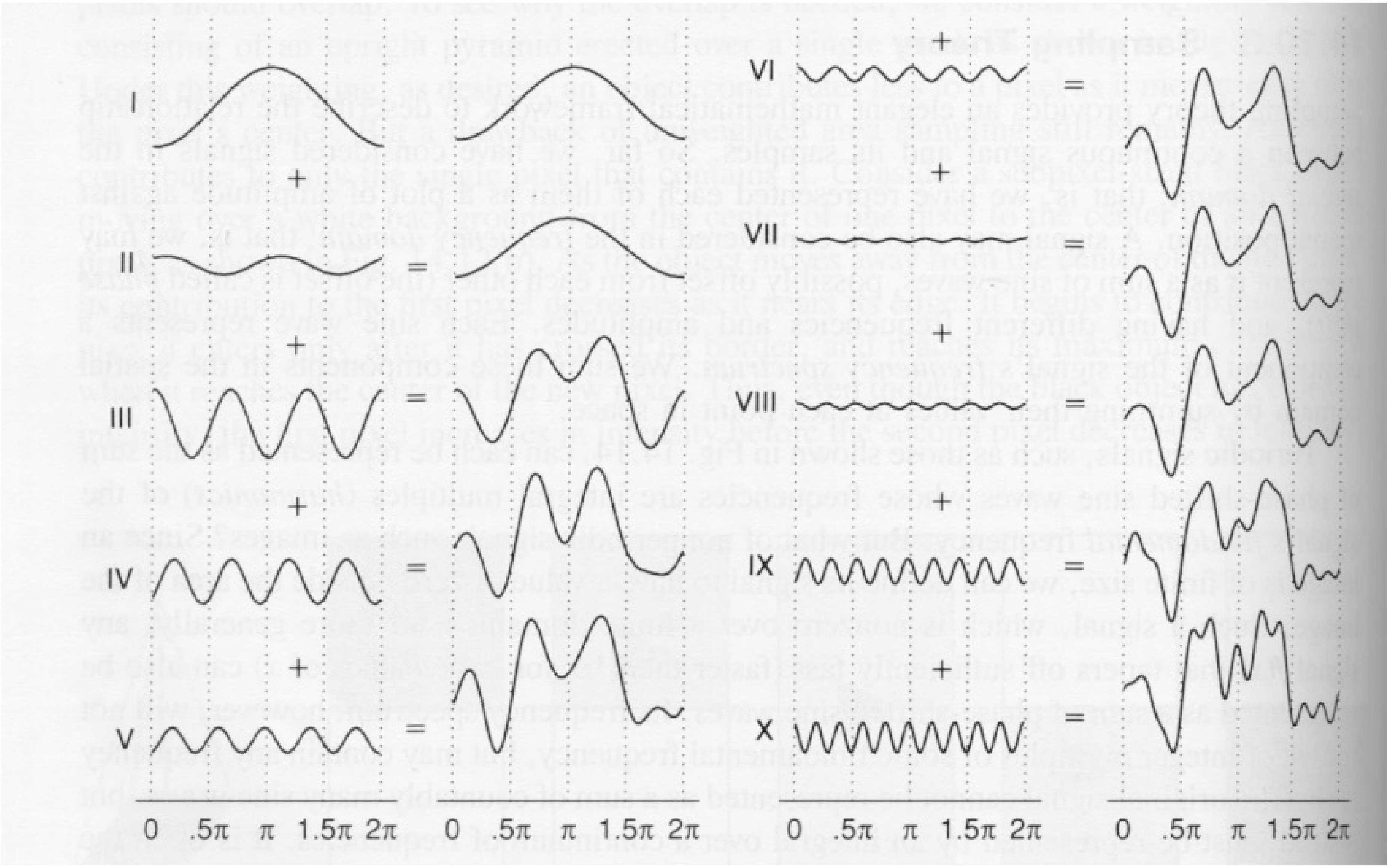
Spatial Domain

- image as spatial signal



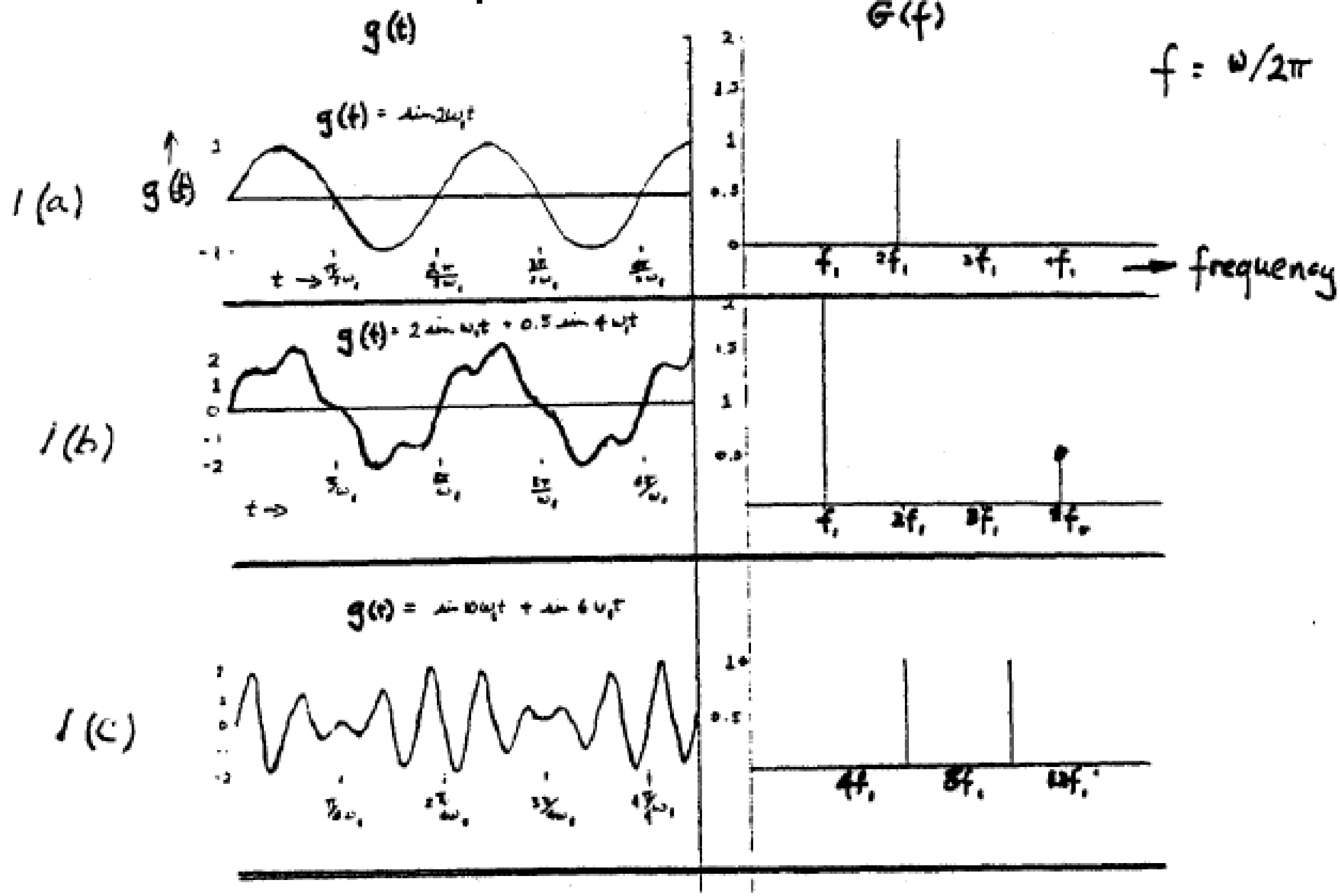
Examples from Foley, van Dam, Feiner, and Hughes

Spatial Domain: Summing Waves



Frequencies: Summing Spikes

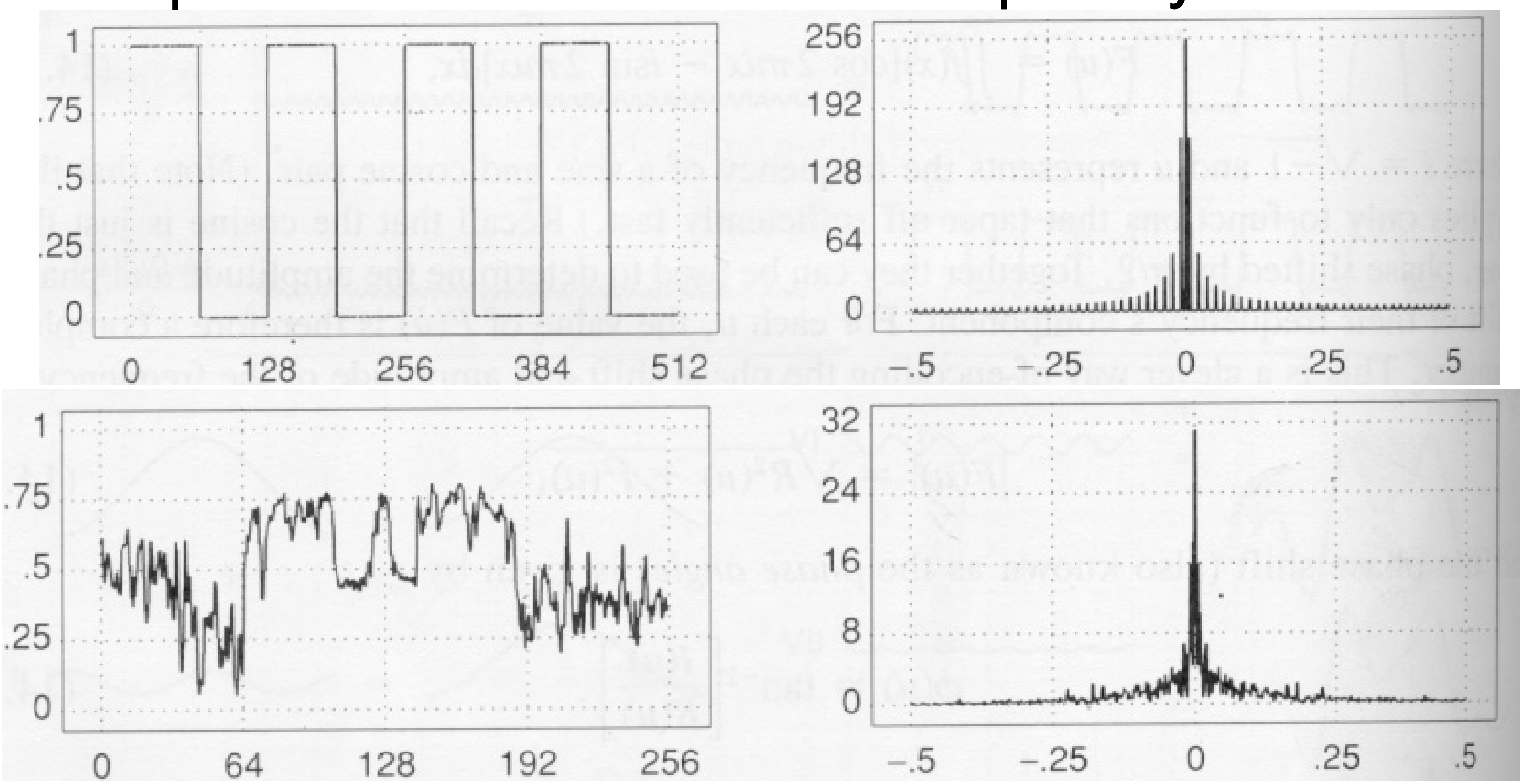
- x: wavelength, y: strength
  - sine wave: impulse



Fourier Transform Examples

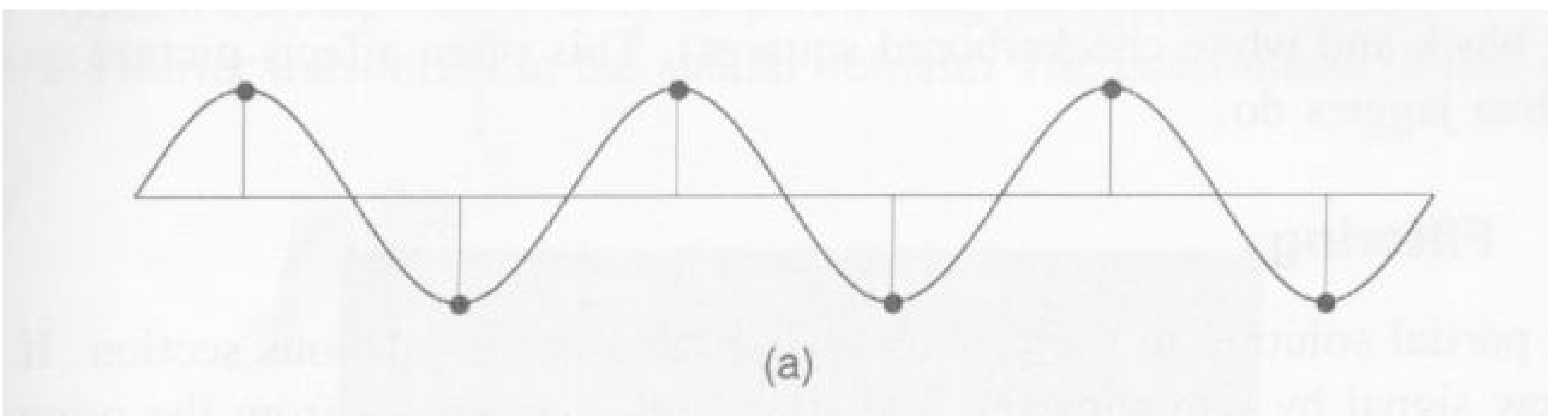
- square wave: infinite train of impulses

spatial domain　　　　frequency domain



Nyquist Rate

- the lower bound on the sampling rate equals twice the highest frequency component in the image's spectrum
- this lower bound is the Nyquist Rate



Falling Below Nyquist Rate

- when sampling below Nyquist Rate, resulting signal looks like a lower-frequency one
  - this is aliasing!

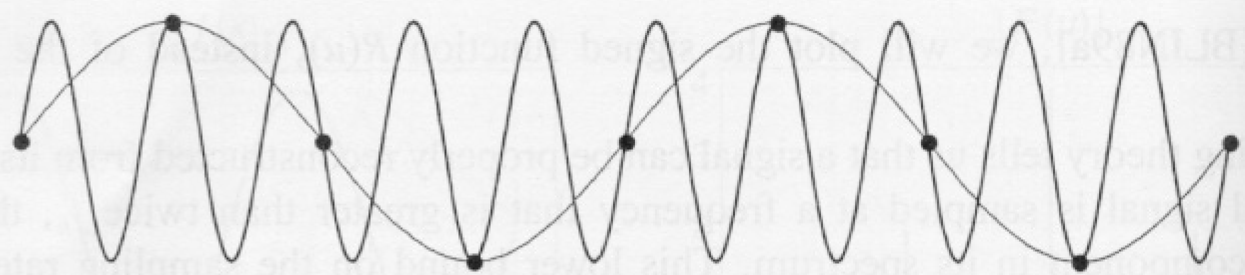


Fig. 14.17 Sampling below the Nyquist rate. (Courtesy of George Wolberg, Columbia University.)

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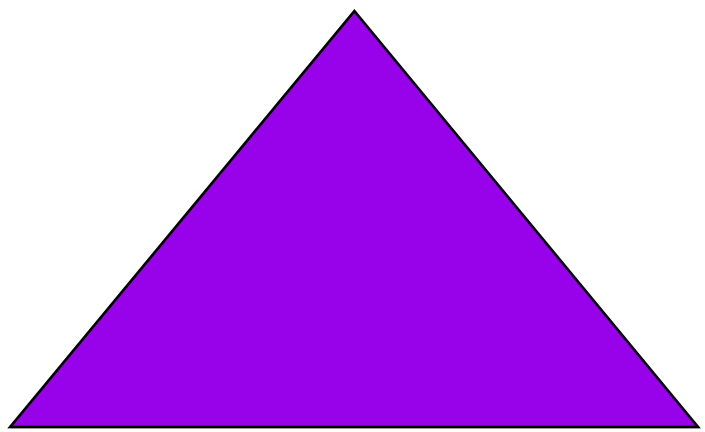
Animation

Animation

algorithm:
simulating physics, parameterizing models



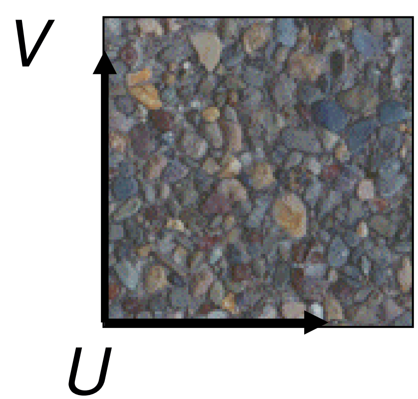
user:
keyframing

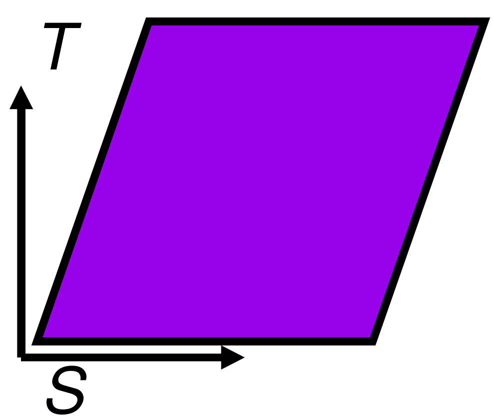
data:
motion capture

Texture Mapping

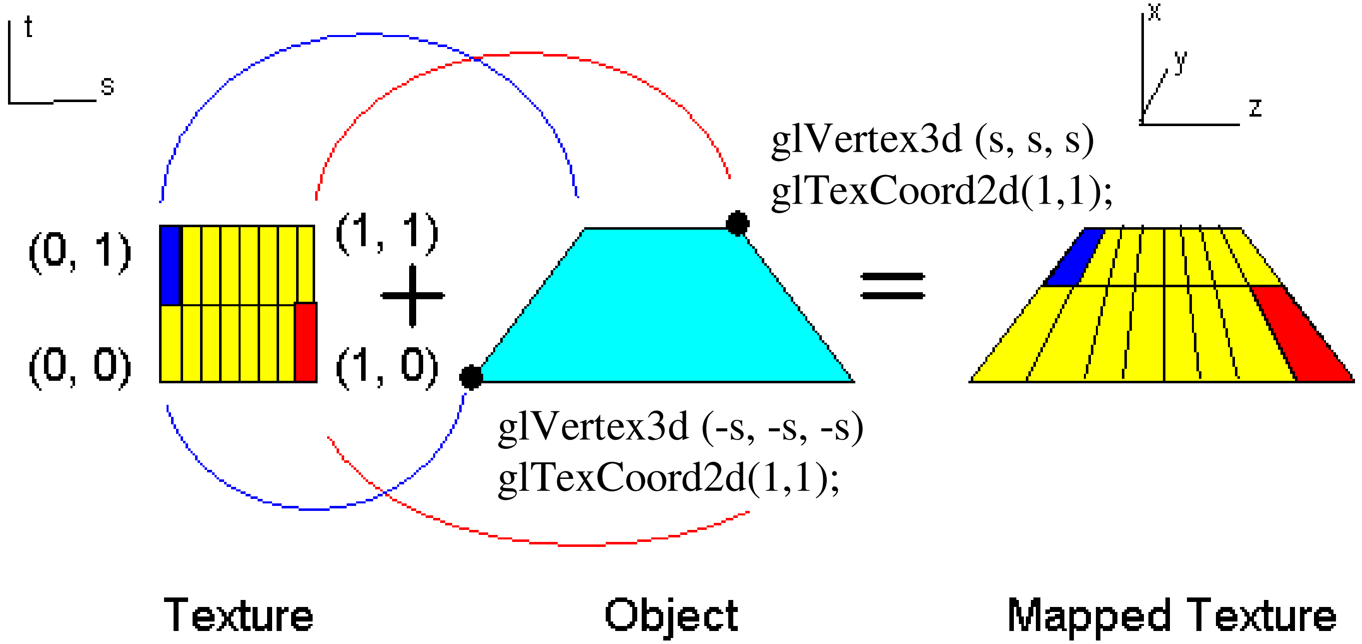
Texture Mapping

- texture map is an image, two-dimensional array of color values (texels)
- texels are specified by texture's (u,v) space
- at each screen pixel, texel can be used to substitute a polygon's surface property (color)
- we must map (u,v) space to polygon's (s, t) space



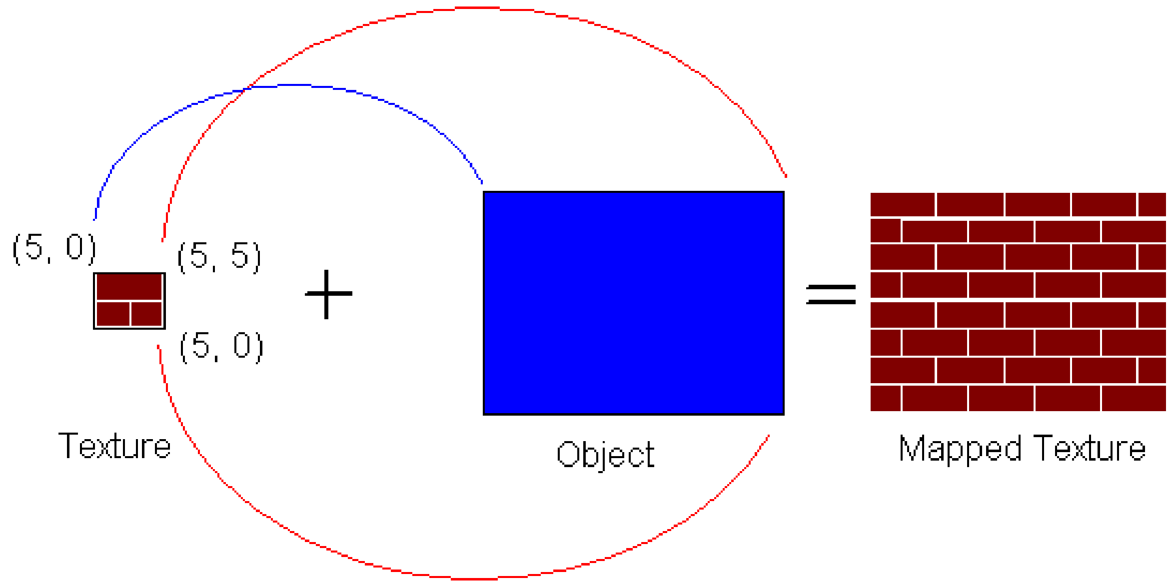


Example Texture Map

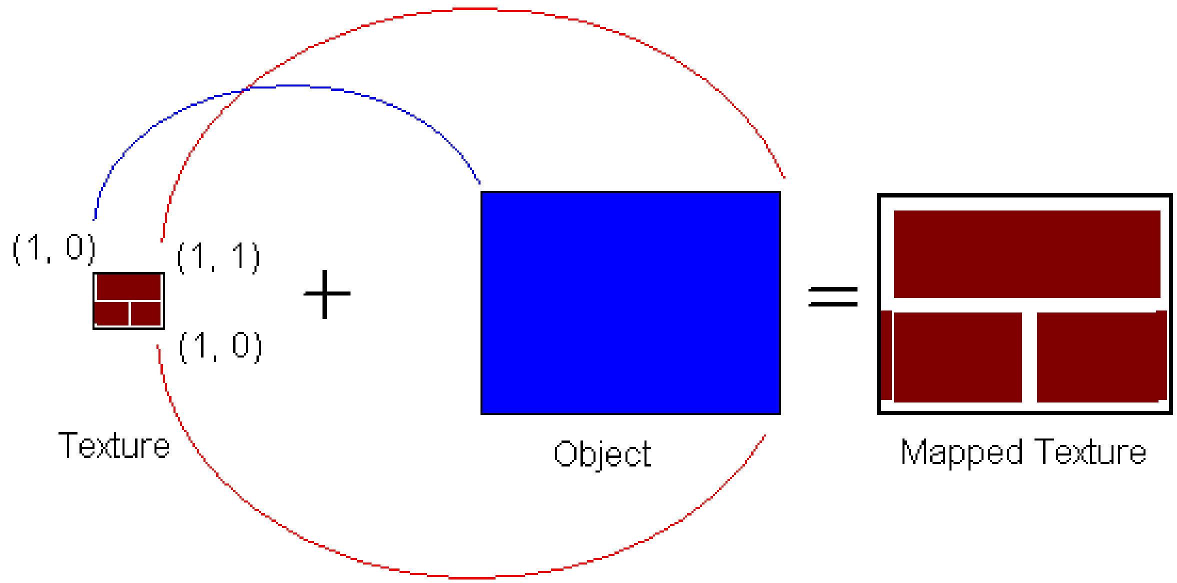


Texture Coordinate Transforms

glVertex3d (s, s, s)
glTexCoord2d(5, 5);



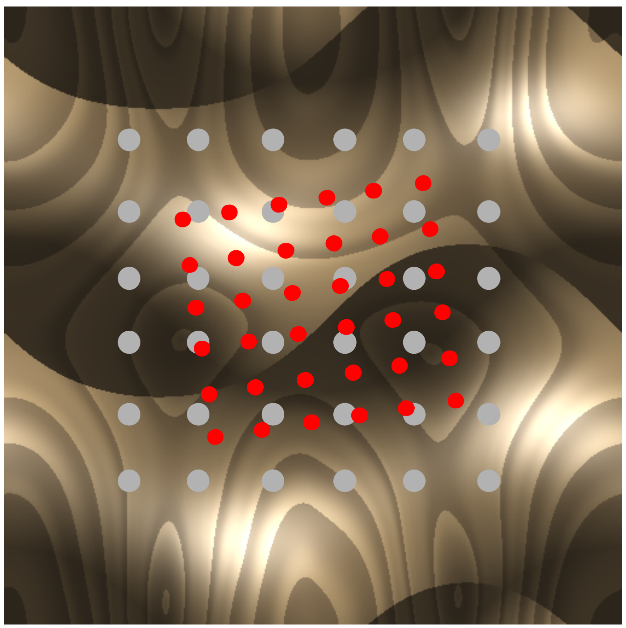
glVertex3d (s, s, s)
glTexCoord2d(1, 1);



Texture Mapping and Filtering

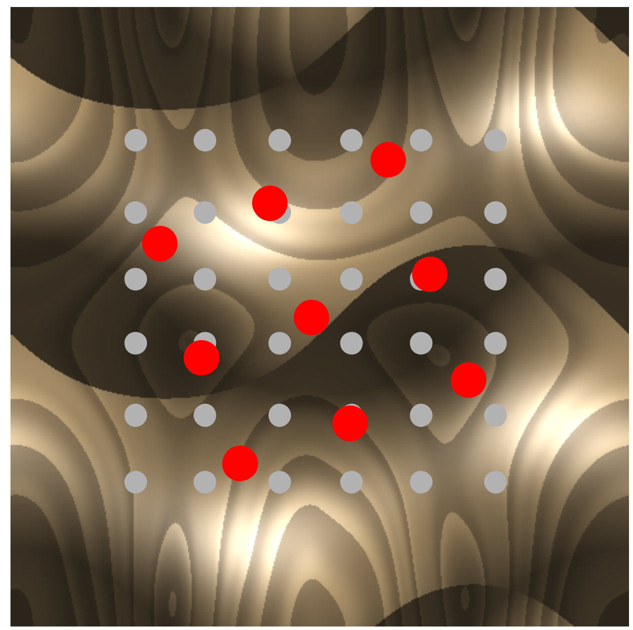
- in practice: 2 cases

texture magnification



interpolation

texture minification



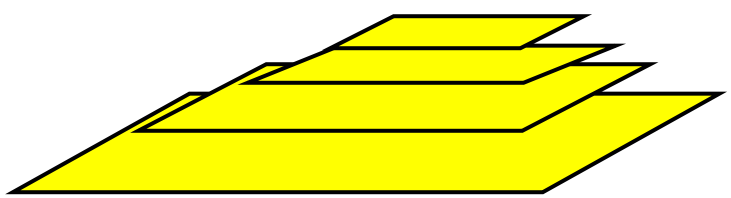
averaging

● Texel

● Pixel

Texture Minification Filters

- solution: precomputation
  - MIP-Mapping (Multum In Parvo)
    - “many things in a small place”
    - store not <u>one</u> texture image, but whole pyramid
    - resolution from level to level varies by factor of two (original resolution … 1x1)
    - every level is correctly filtered for its resolution



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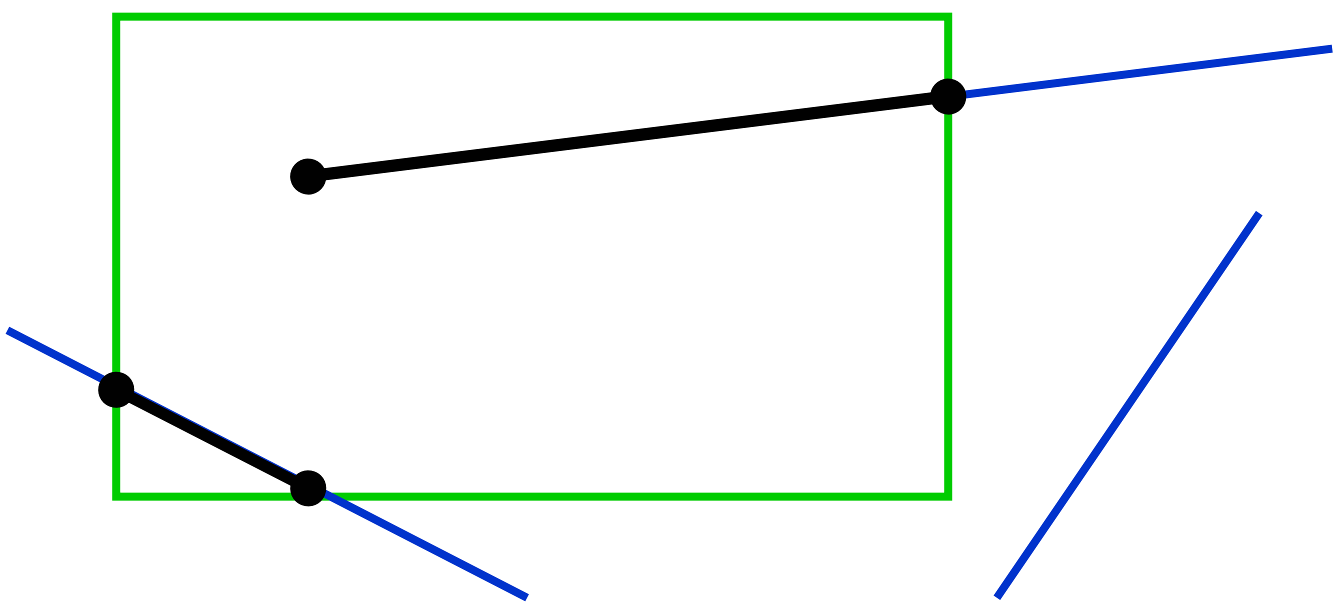
Clipping

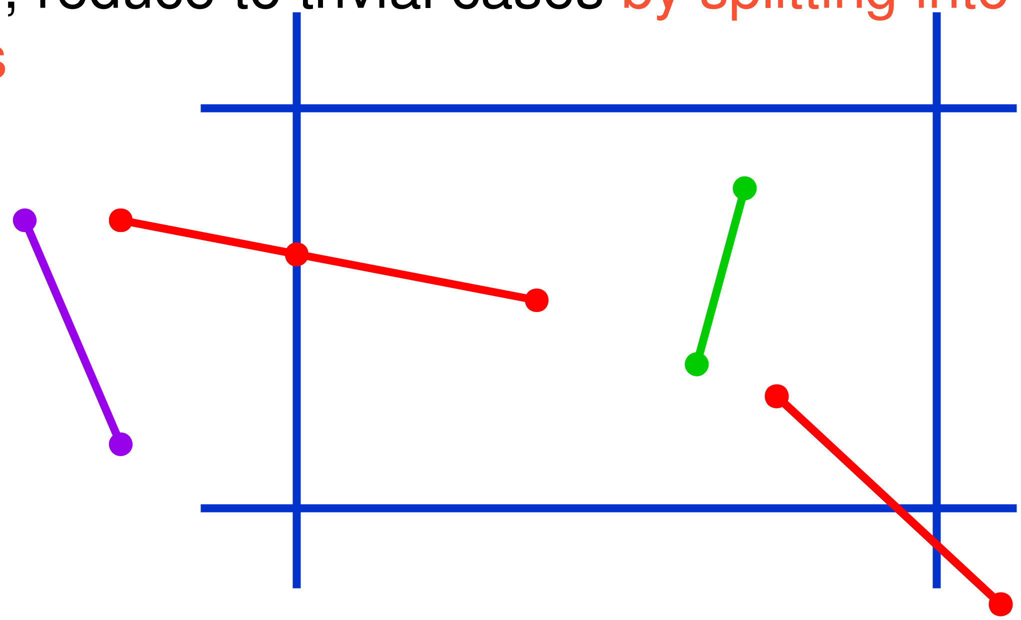
Clipping

- analytically calculating the portions of primitives within the viewport



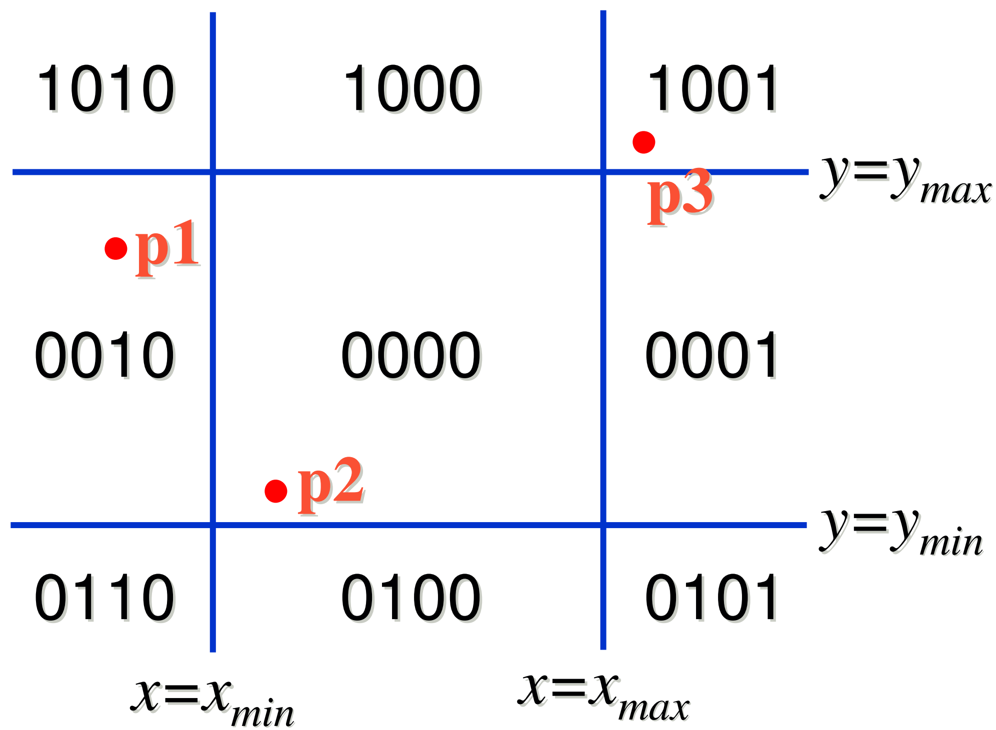
Clipping Lines To Viewport

- combining trivial accepts/rejects
  - trivially accept lines with both endpoints inside all edges of the viewport
  - trivially reject lines with both endpoints outside the same edge of the viewport
  - otherwise, reduce to trivial cases by splitting into two segments



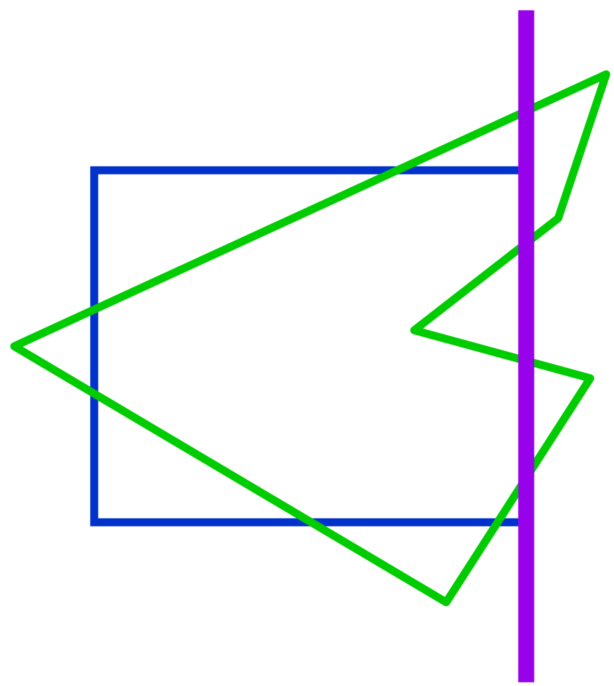
Cohen-Sutherland Line Clipping

- outcodes
  - 4 flags encoding position of a point relative to top, bottom, left, and right boundary
    - *OC(p1)=0010*
    - *OC(p2)=0000*
    - *OC(p3)=1001*



Sutherland-Hodgeman Polygon Clipping

- basic idea:
  - consider each edge of the viewport individually
  - clip the polygon against the edge equation
  - after doing all edges, the polygon is fully clipped



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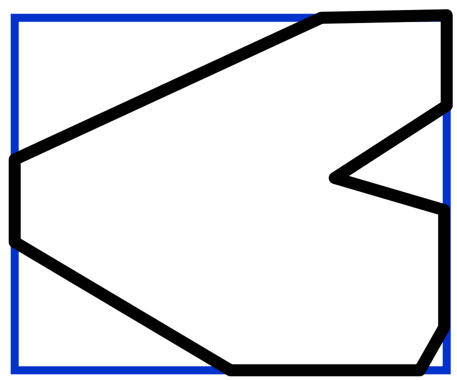
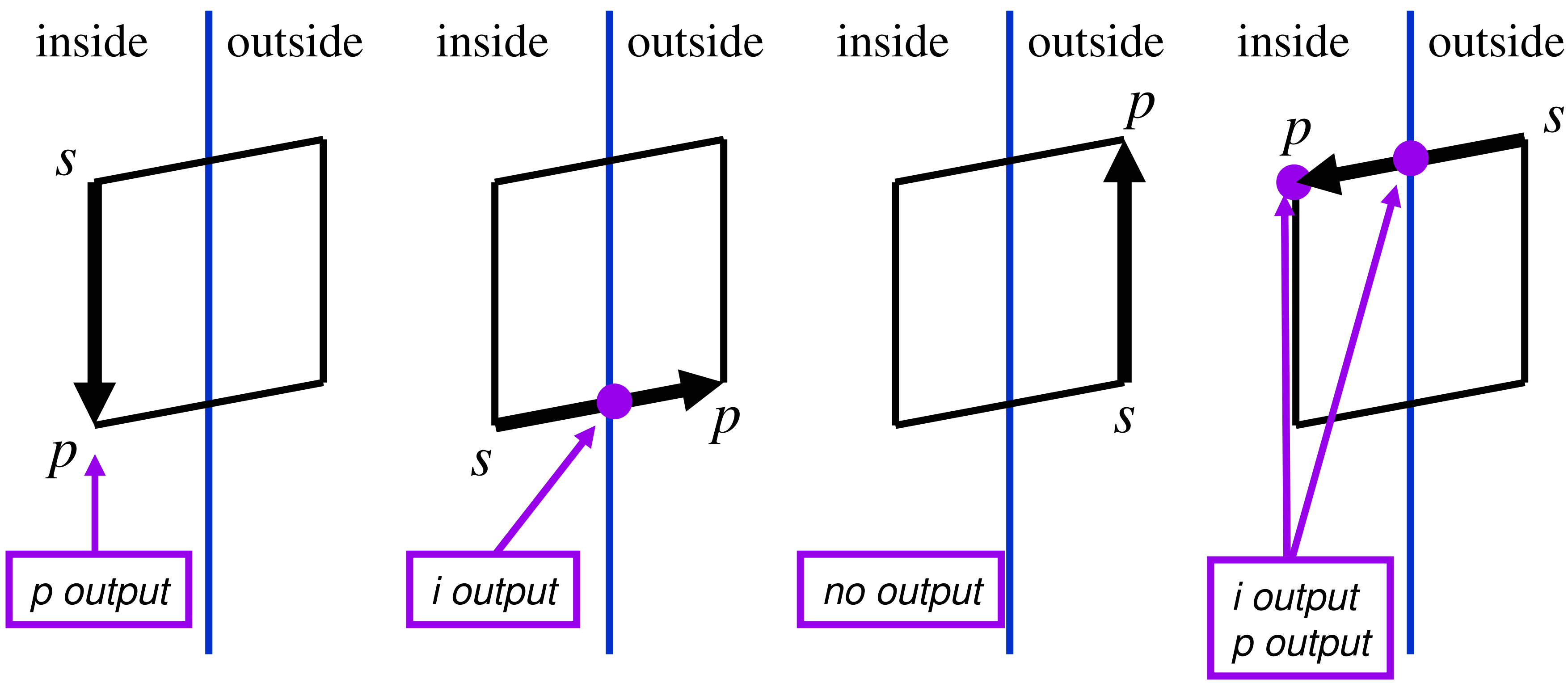


Sutherland-Hodgeman Clipping

- edge from *s* to *p* takes one of four cases:
  (blue line can be a line or a plane)



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Rotation/Quaternions

Rotation Methods

- 3x3 matrices
  - good: simple. bad: drifting, can’t interpolate
- Euler angles
  - good: can interpolate, no drift
  - bad: gimbal lock
- axis-angle
  - good: no gimbal lock, can interpolate
  - bad: can’t concatenate
- quaternions
  - good: solve all problems. bad: complex

Quaternions

- quaternion is a 4-D unit vector q = [x y z w]
  - lies on the unit hypersphere $x^2 + y^2 + z^2 + w^2 = 1$
- for rotation about (unit) axis v by angle θ
  - vector part = (sin θ/2) *v* = *[x y z]*
  - scalar part = (cos θ/2) = *w*
- rotation matrix

$$\begin{bmatrix} 1-2y^2-2z^2 & 2xy+2wz & 2xz-2wy \\ 2xy-2wz & 1-2x^2-2z^2 & 2yz+2wx \\ 2xz+2wy & 2yz-2wx & 1-2x^2-2y^2 \end{bmatrix}$$

- quaternion multiplication $q_1 * q_2 =$

$[\mathbf{v_1}, w_1] * [\mathbf{v_2}, w_2] = [(w_1 v_2 + w_2 v_1 + (v_1 \times v_2)), w_1 w_2 - v_1 . v_2]$

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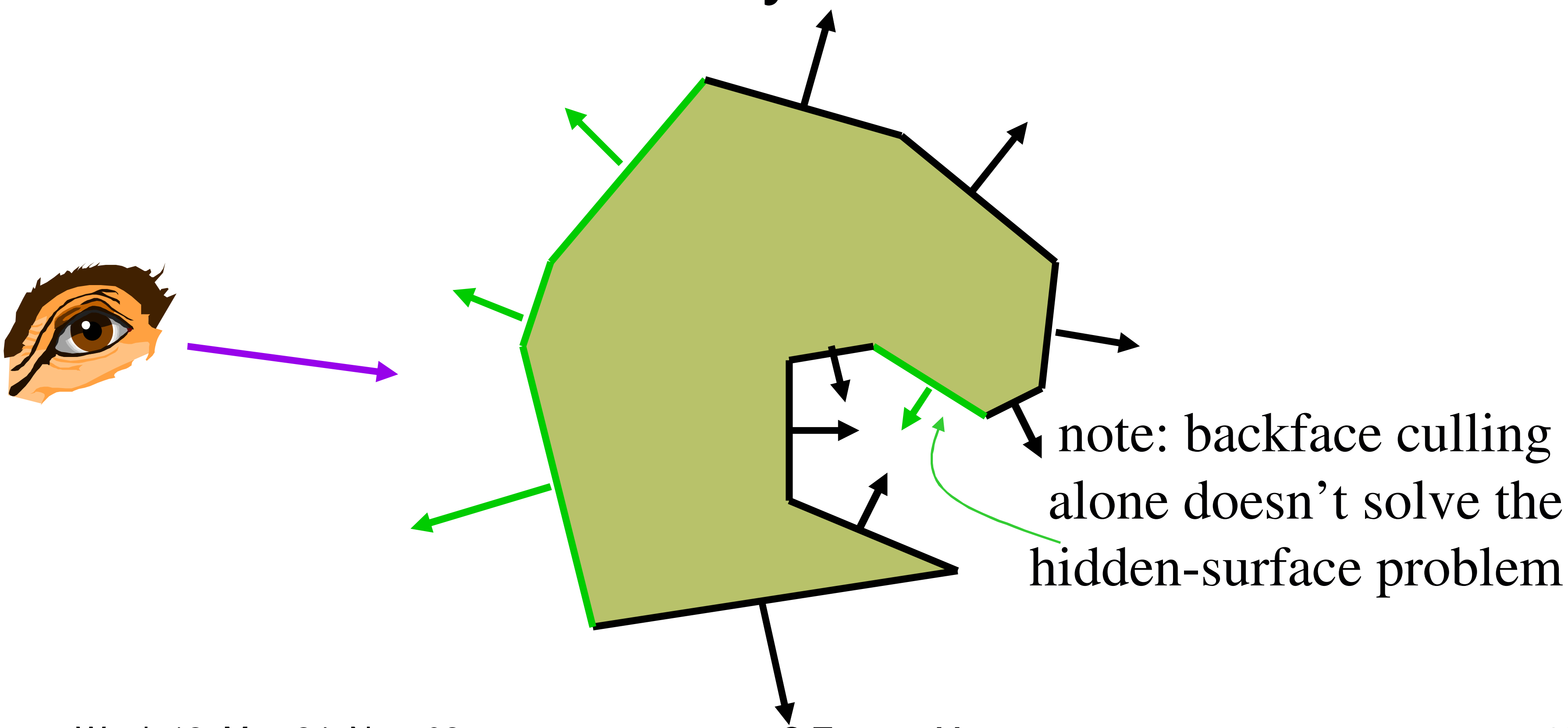
Visibility

Invisible Primitives

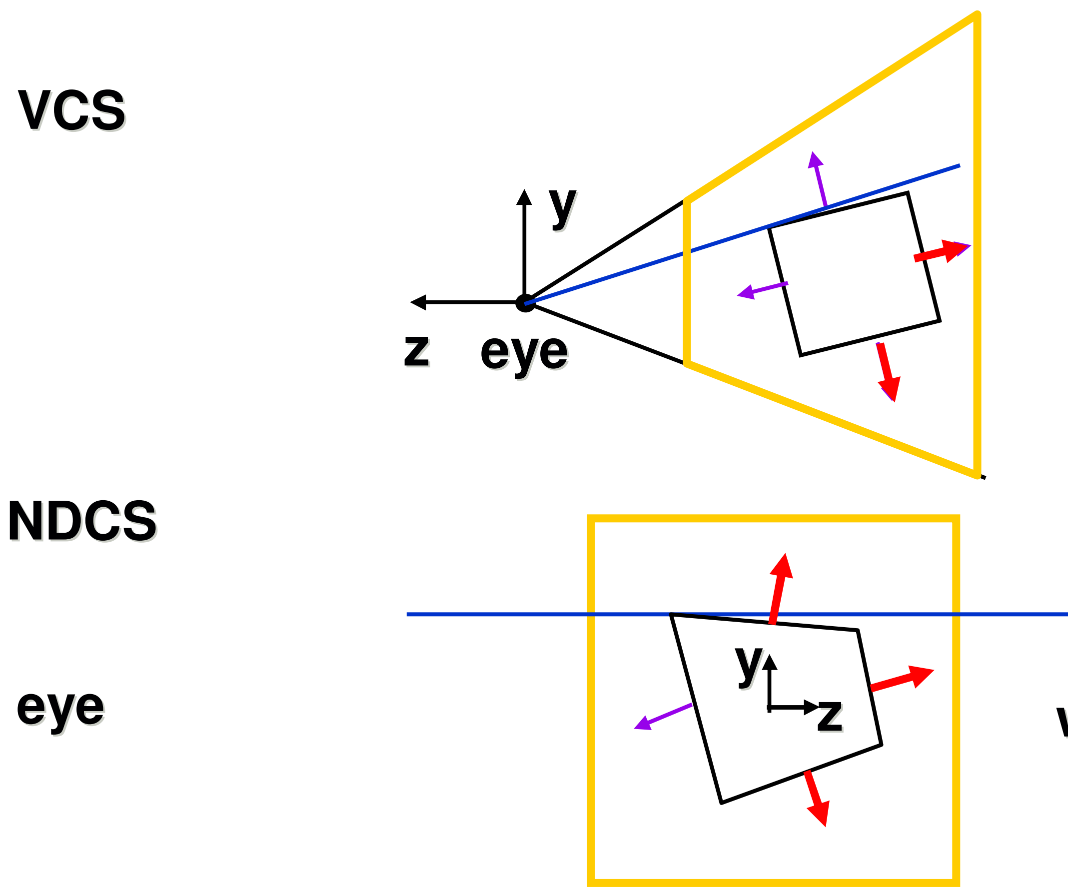
- why might a polygon be invisible?
  - polygon outside the *field of view / frustum*
    - clipping
  - polygon is *backfacing*
    - backface culling
  - polygon is *occluded* by object(s) nearer the viewpoint
    - hidden surface removal

Back-Face Culling

- on the surface of a closed manifold, polygons whose normals point away from the camera are always occluded:



Back-face Culling: NDCS



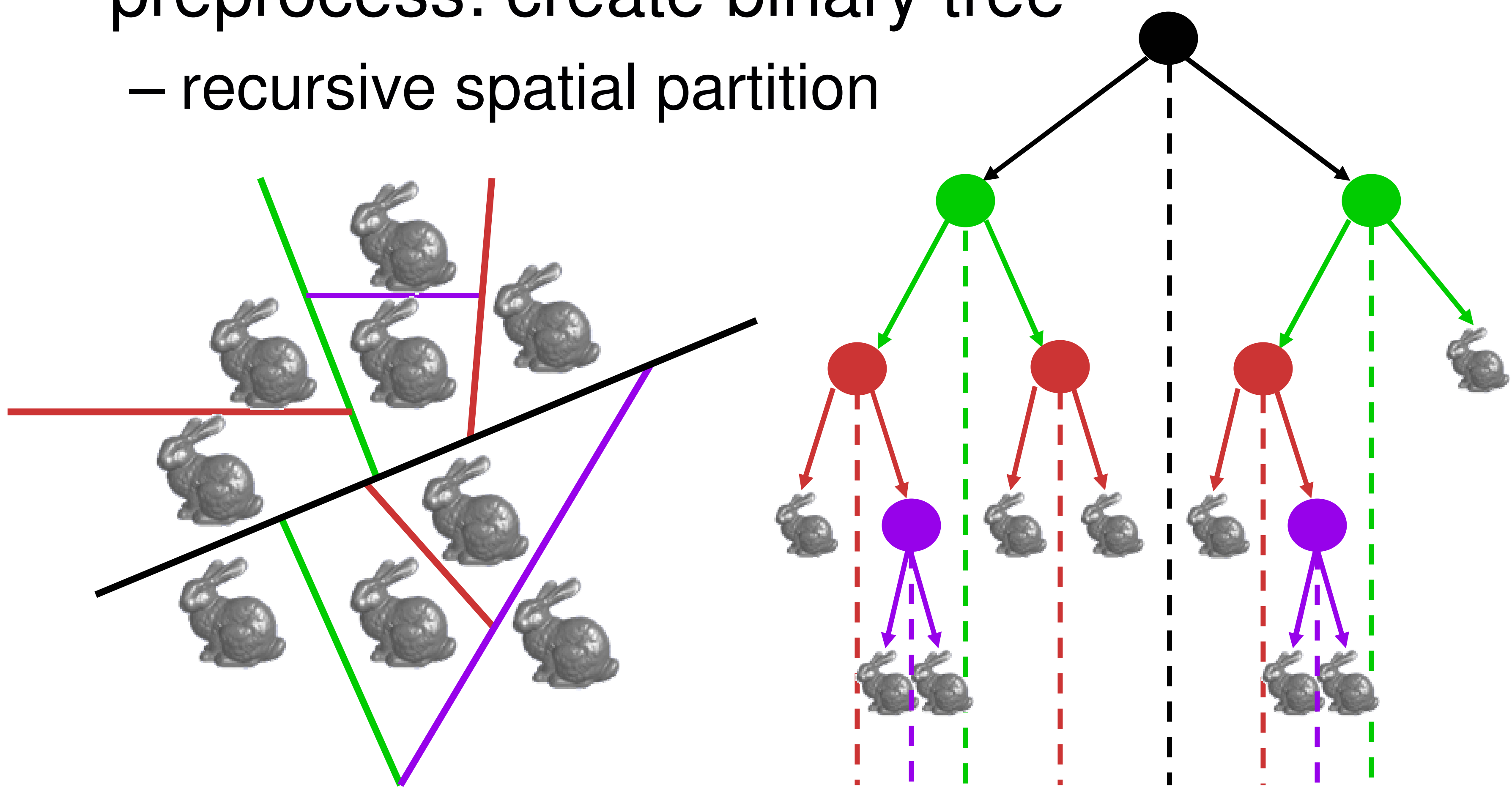
works to cull if $N_Z > 0$

Painter's Algorithm

- draw objects from back to front
- problems: no valid visibility order for
  - intersecting polygons
  - cycles of non-intersecting polygons possible

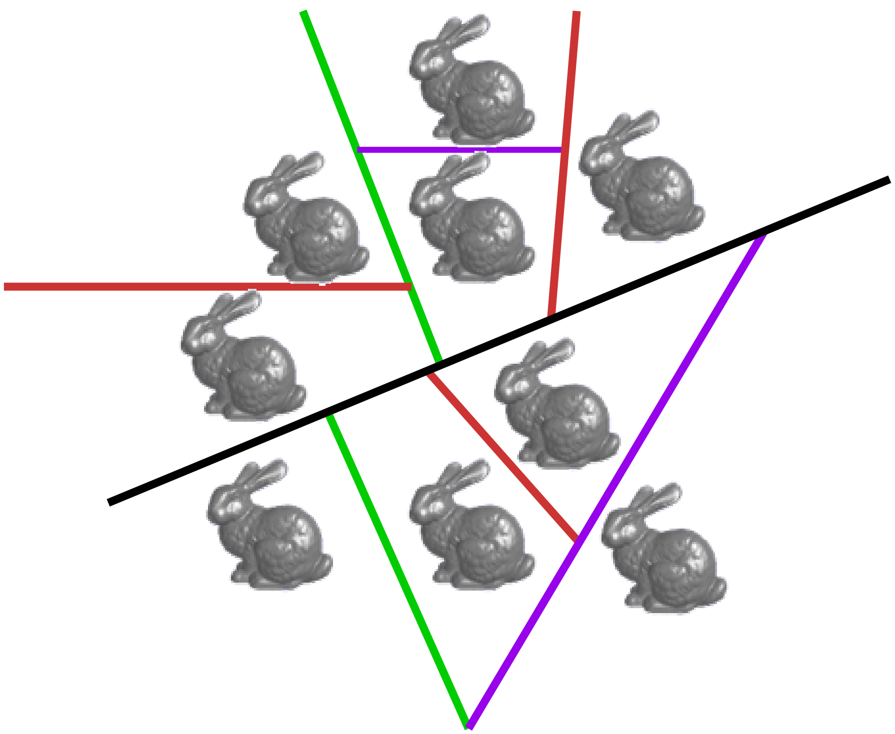
BSP Trees

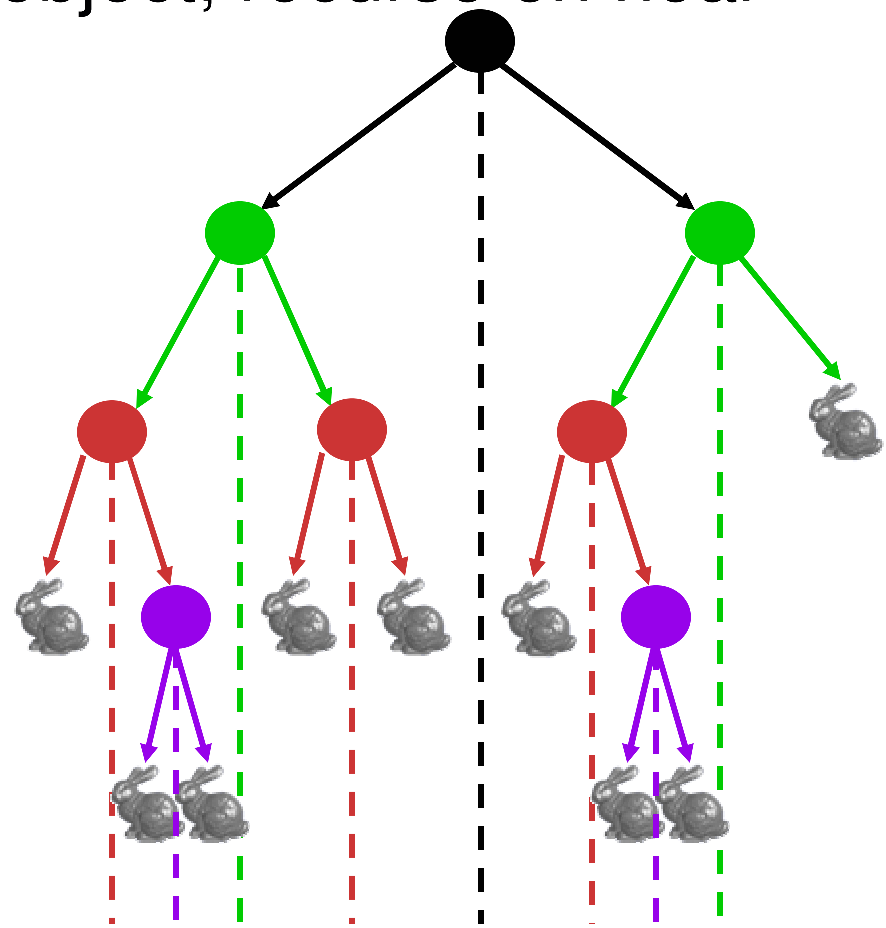
- preprocess: create binary tree
  - recursive spatial partition



BSP Trees

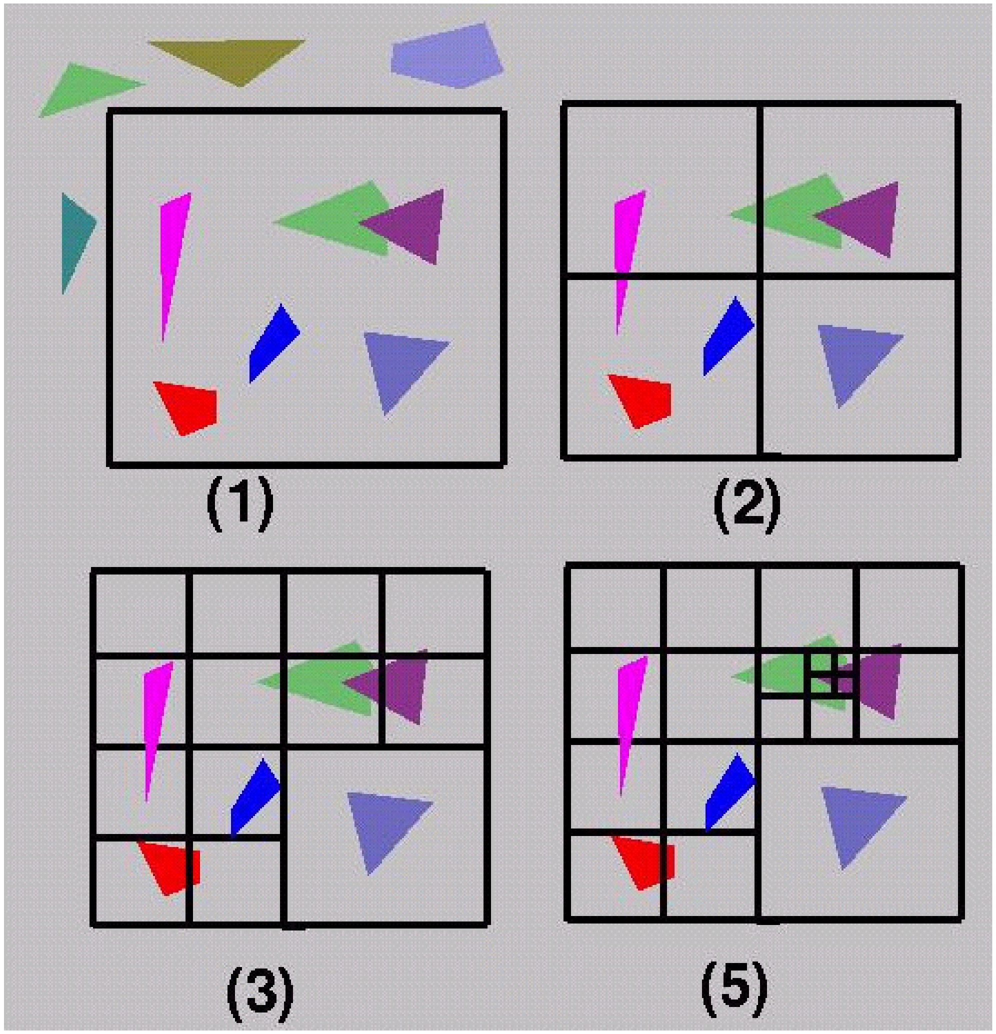
- runtime: traverse tree
  - check node’s plane vs. eyepoint
  - recurse on far, draw object, recurse on near





Warnock's Algorithm

- recursive
  - start at root viewport of entire window
  - clip objects to current viewport
  - trivial if 0 or 1 objects
  - subdivide if more
  - stop if trivial or down to one pixel



The Z-Buffer Algorithm

- augment color framebuffer with Z-buffer or depth buffer which stores Z value at each pixel
  - at frame beginning, initialize all pixel depths to ∞
  - when rasterizing, interpolate depth (Z) across polygon and store in pixel of Z-buffer
  - suppress writing to a pixel if its Z value is more distant than the Z value already stored there
  - depth-buffer essentially stores $1/z$, rather than z

Hidden Surface Removal

- image-space algorithms
  - Z-buffer, Warnock's
  - perform visibility test for every pixel independently
  - performed late in rendering pipeline, resolution dependent
- object-space algorithms
  - painter's algorithm: depth-sorting, BSP trees
  - determine visibility on a polygon level in camera coordinates
  - early in rendering pipeline (after clipping)
  - resolution independent
  - expensive

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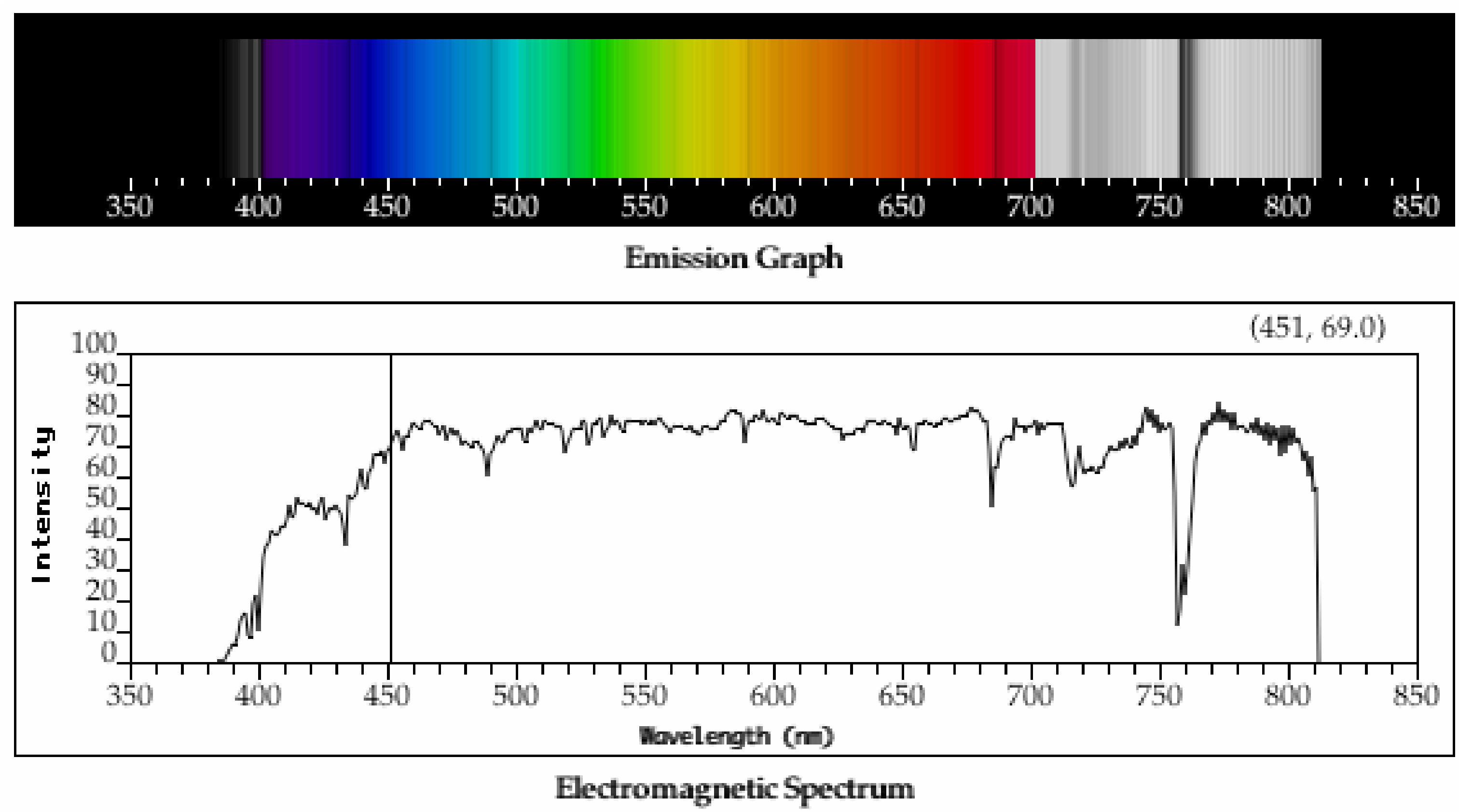
Color

Sunlight Spectrum

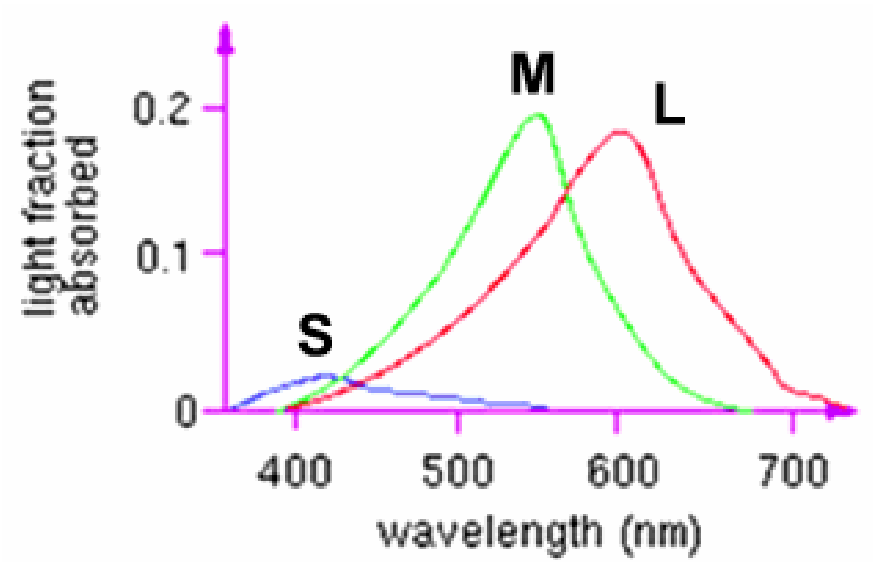


Humans and Light

- when we view a source of light, our eyes respond respond to
  - hue: the color we see (red, green, purple)
    - dominant frequency
  - saturation: how far is color from grey
    - how far is the color from gray (pink is less saturated than red, sky blue is less saturated than royal blue)
  - brightness: how bright is the color
    - how bright are the lights illuminating the object?

Trichromacy

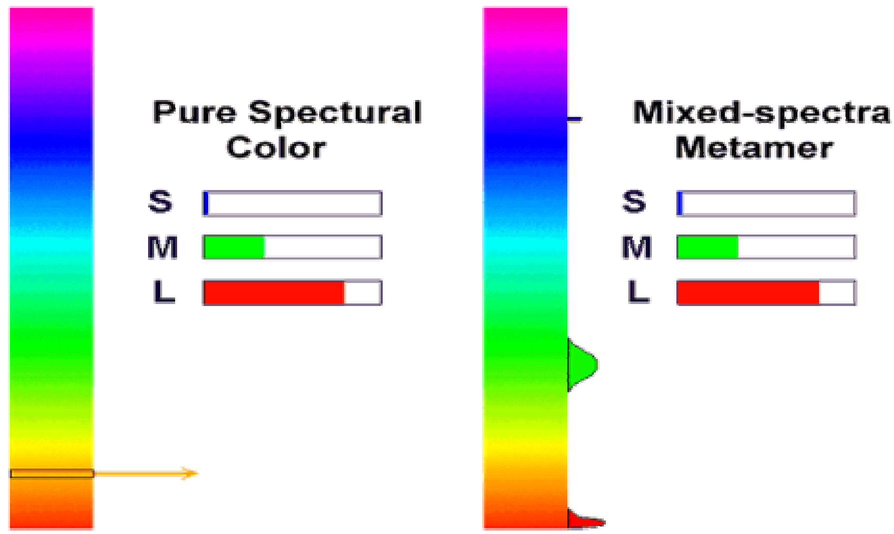
- three types of cones
  – L or R, most sensitive to red light (610 nm)
  – M or G, most sensitive to green light (560 nm)
  – S or B, most sensitive to blue light (430 nm)



  – color blindness results from missing cone type(s)

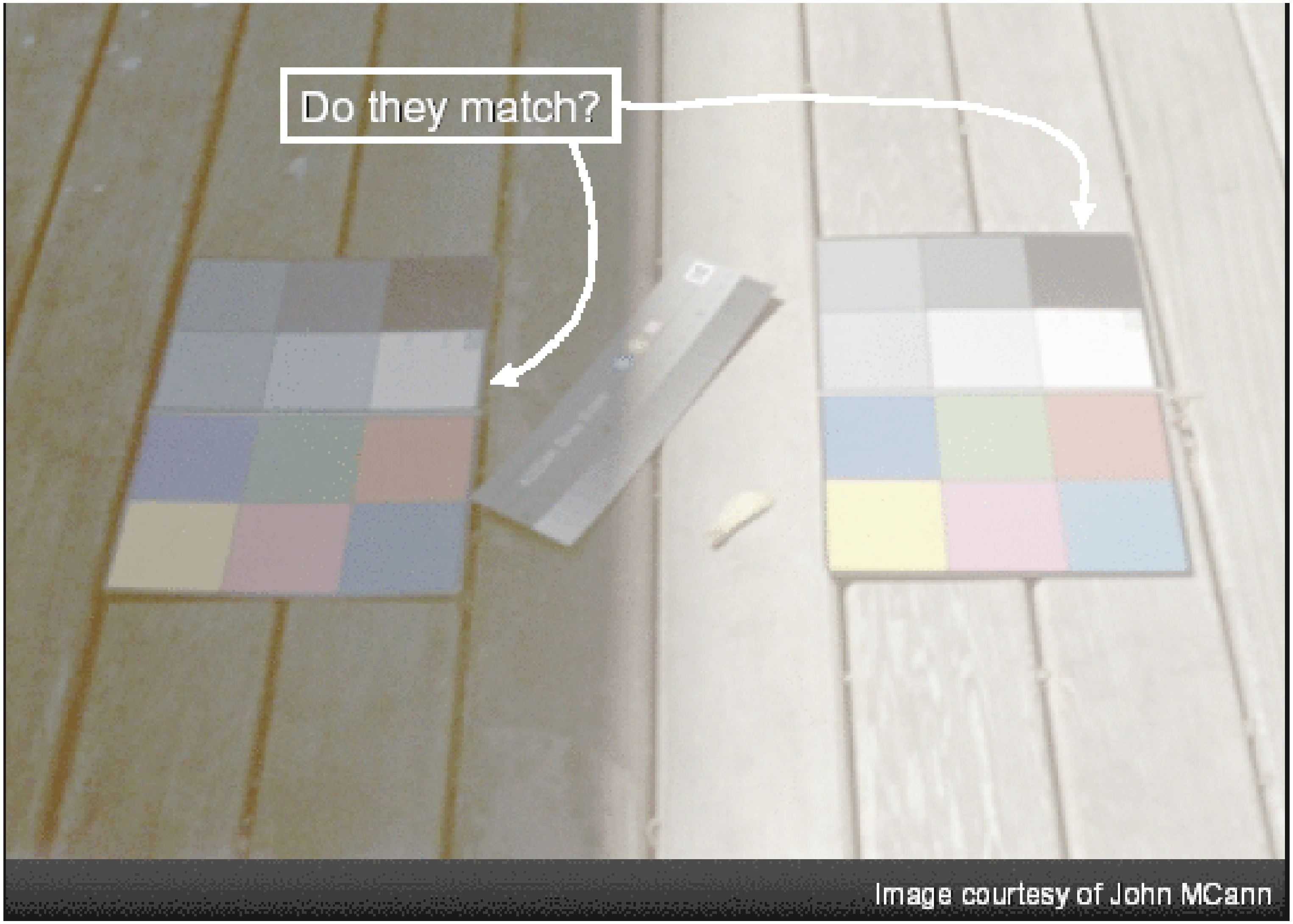
Metamers

a given perceptual sensation of color derives from the stimulus of all three cone types

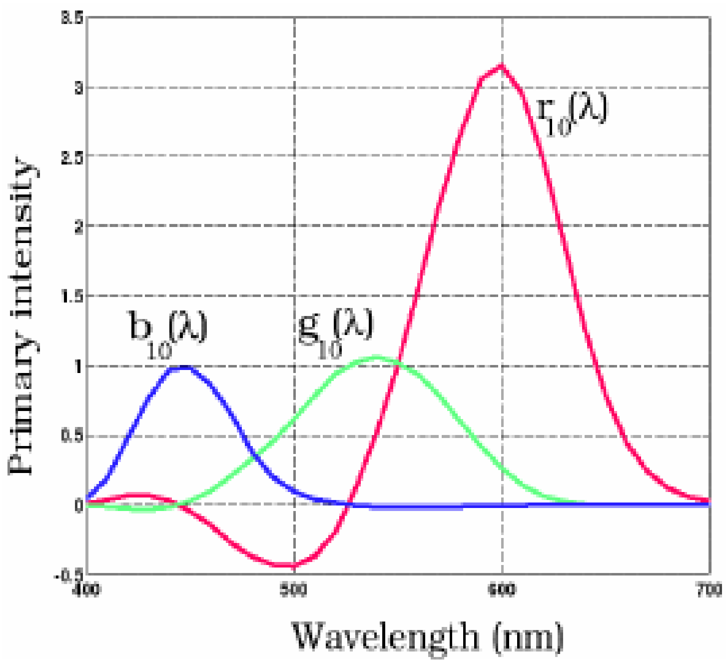


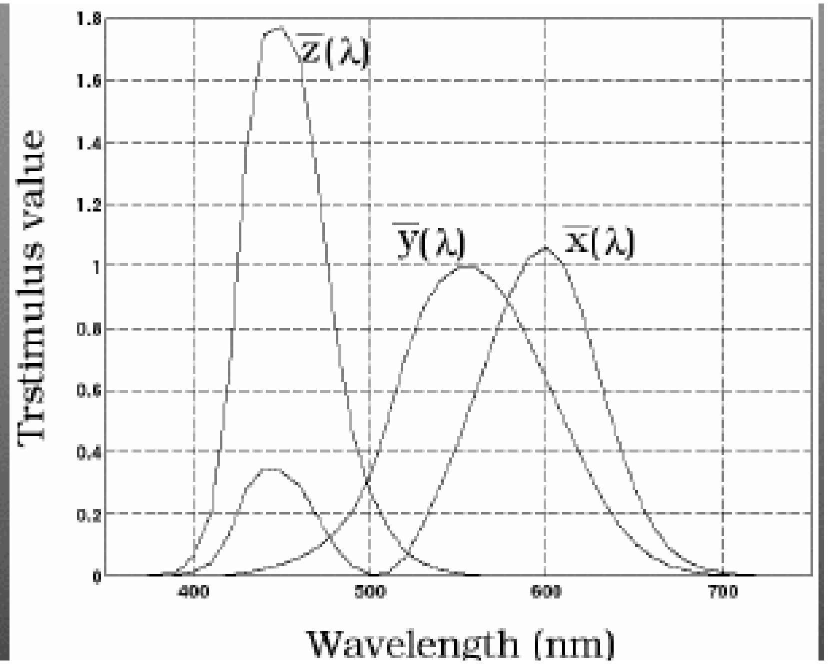
- identical perceptions of color can thus be caused by very different spectra

Color Constancy



Measured vs. CIE Color Spaces



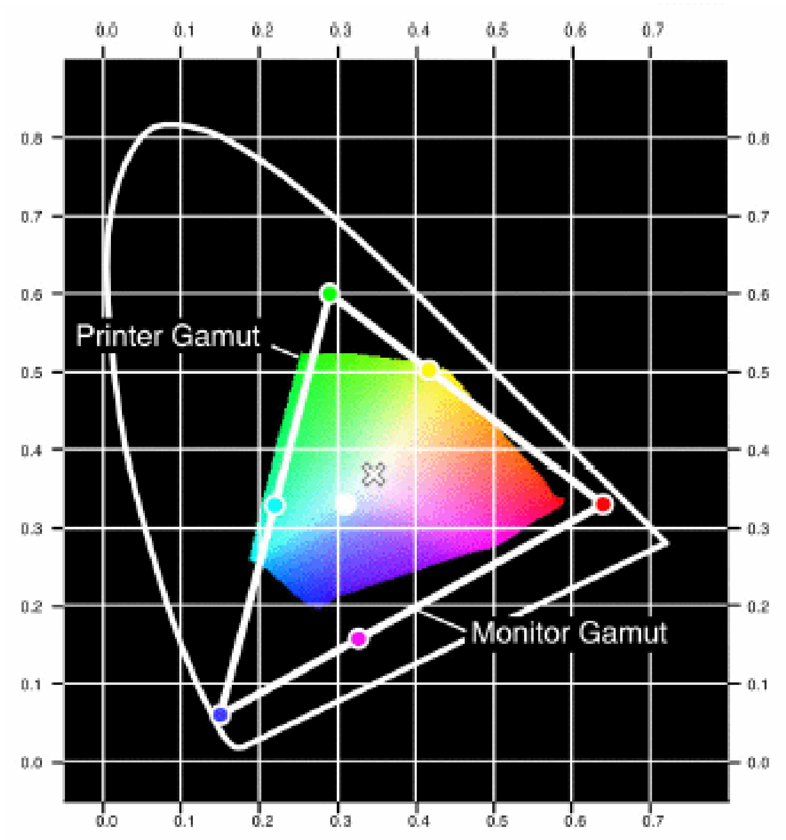


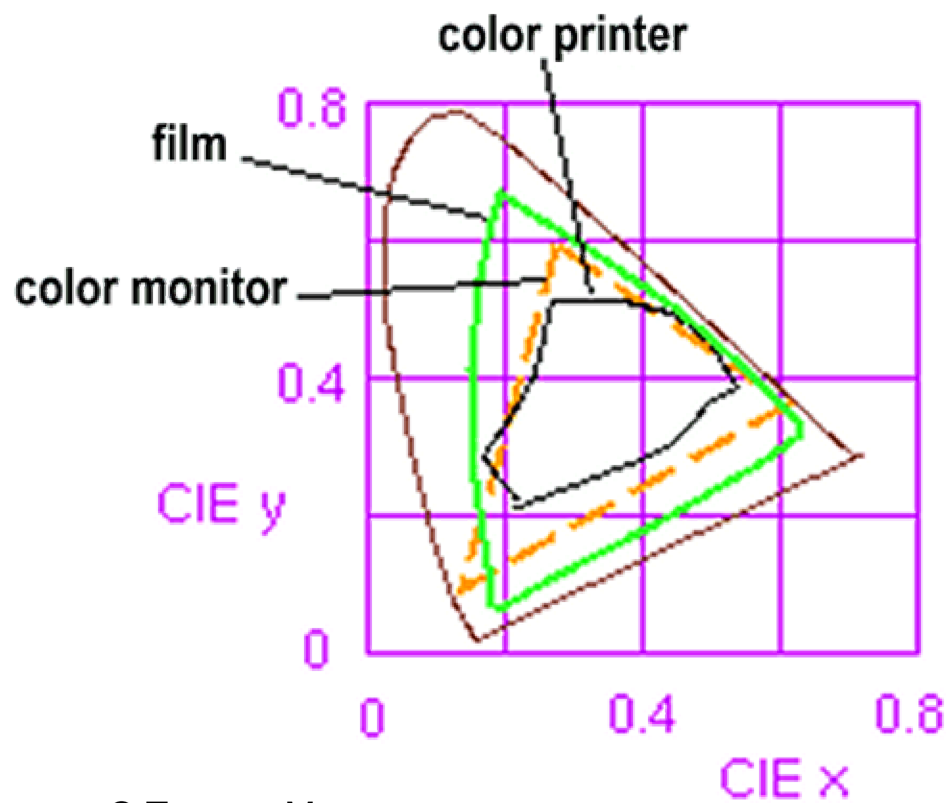
- measured basis
  - monochromatic lights
  - physical observations
  - negative lobes

- transformed basis
  - “imaginary” lights
  - all positive, unit area
  - Y is luminance

Device Color Gamuts

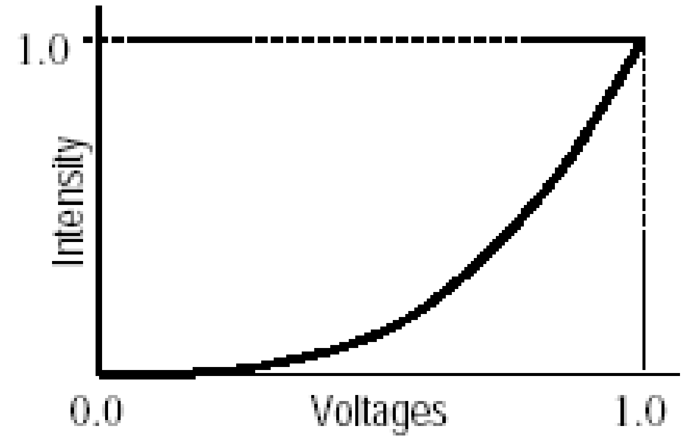
- use CIE chromaticity diagram to compare the gamuts of various devices

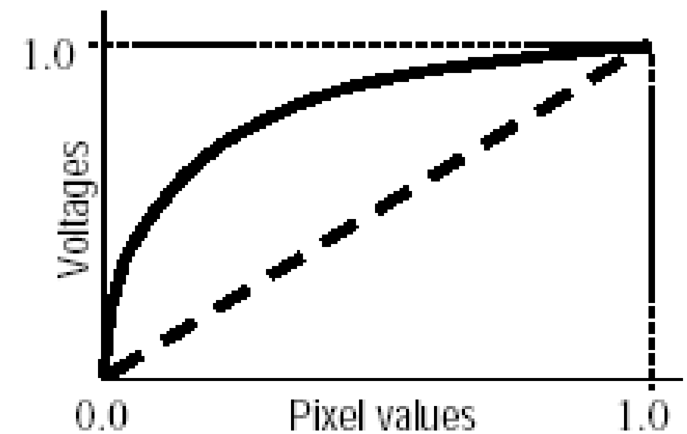




The Gamma Problem

- device gamma
  - monitor: $\mathtt{I} = A(k_1 D + k_2 V)^{\gamma}$
  - typical monitor γ=2.5
  - LCD: nearly linear
- OS gamma
  - defined by operating system
  - inverse gamma curve $\mathtt{I}^{1/\gamma}$
  - "gamma correction"





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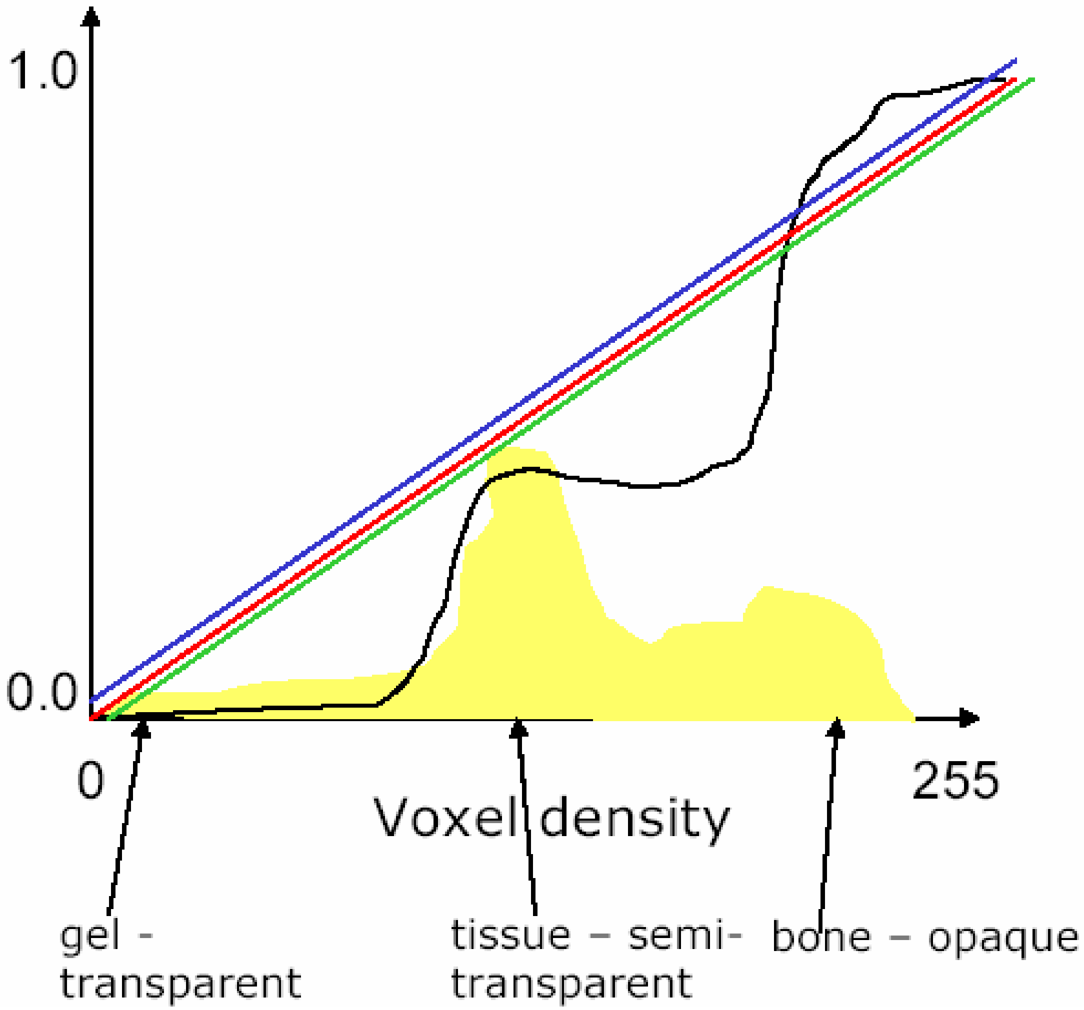
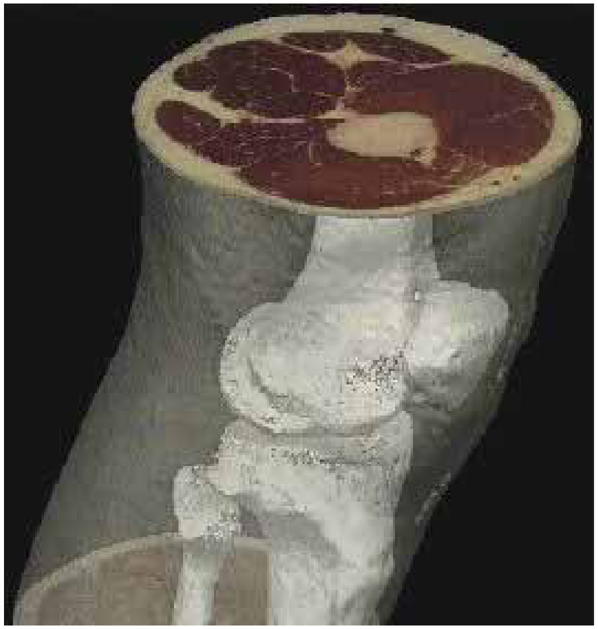
Scientific Visualization

Transfer Functions

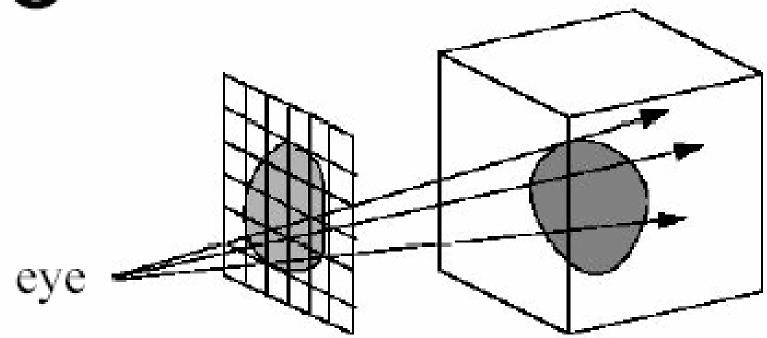




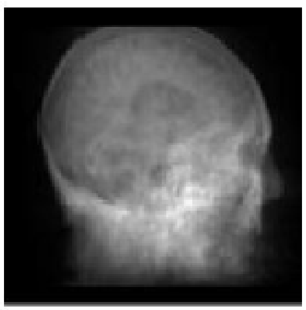
- classification of 3D array of voxels

Volume Rendering Modes

- For each pixel in the image, a ray is cast into the volume:

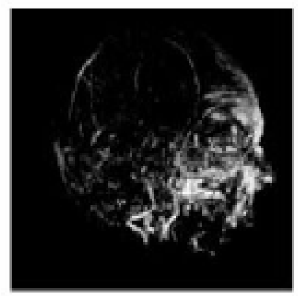


- Four main volume rendering modes exist:



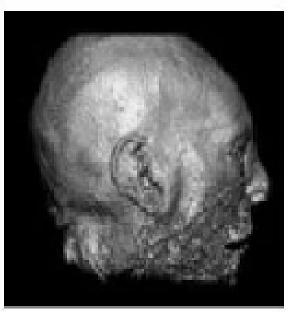
X-Ray:

Rays sum contributions along their path linearly



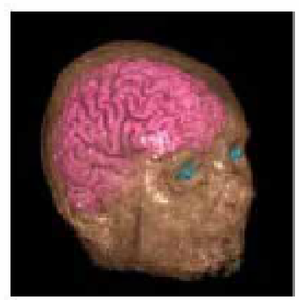
Maximum Intensity Projection:

A pixel stores the largest intensity values along its ray



Iso-surface:

Rays **composite** contributions only from voxels of a certain intensity defining a surface

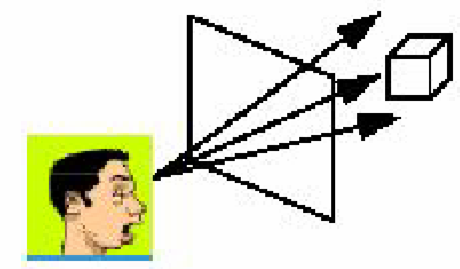


Full-volume:

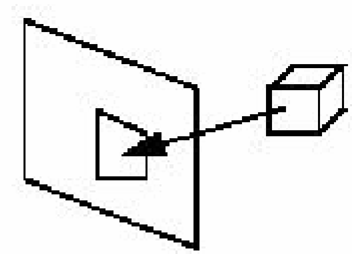
Rays **composite** contributions along their path linearly

Volume Rendering Algorithms

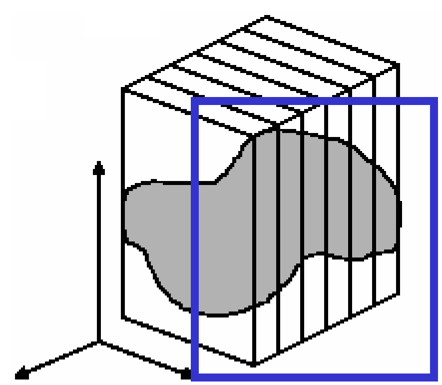
- ray casting
  - image order, forward viewing



- splatting
  - object order, backward viewing



- texture mapping hardware
  - object order
  - back-to-front compositing



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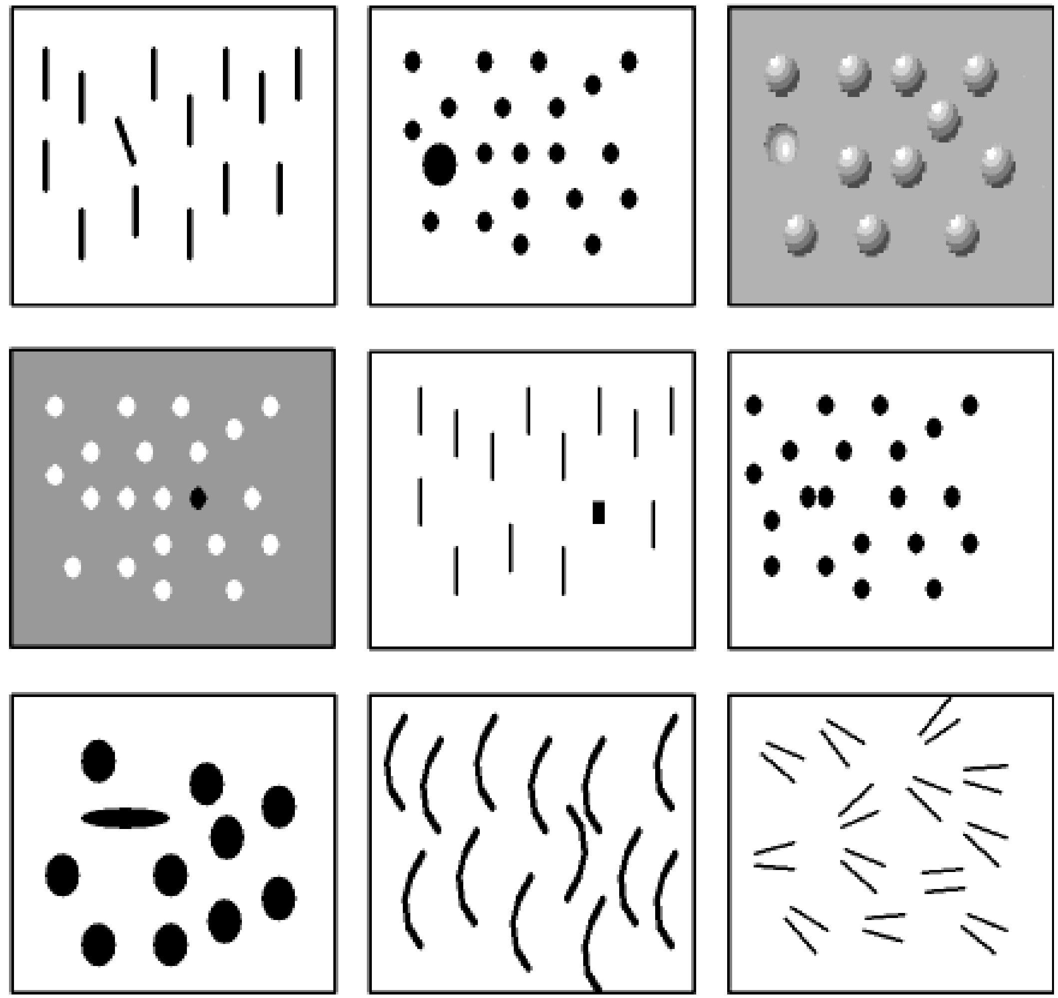
Information Visualization

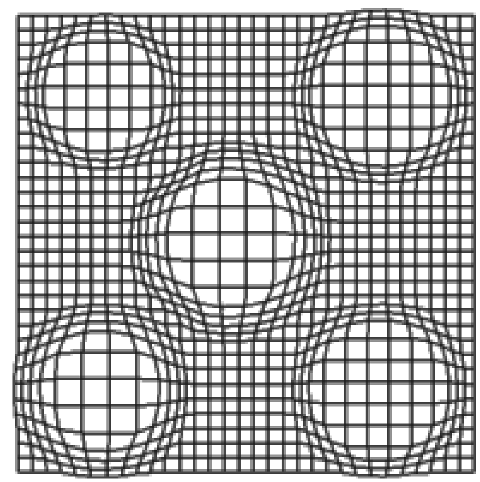
Preattentive Visual Dimensions

- visual popout independent of distractor count
  - hue
  - shape
  - texture
  - length
  - width
  - size
  - orientation
  - curvature
  - intersection
  - intensity
  - flicker
  - direction of motion
  - stereoscopic depth
  - lighting direction



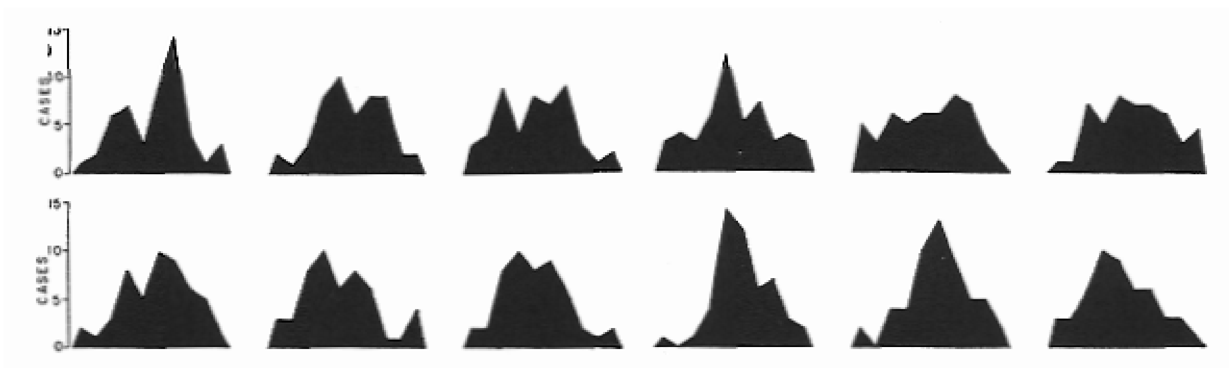
Overview and Detail

- problem: getting lost
  - 1 window: lose track of navigation history
  - 2 windows: see overview and detail both
  - Focus+Context
    - 1 window combines overview and detail
    - carefully chosen distortion



Comparison

- array of small multiples
  - side by side comparison easier than temporal



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Displays and Devices

Display Technologies

- CRT: Cathode Ray Tubes
- LCD: Liquid Crystal Displays
- plasma display panels
- DMD/DLP: micromirror array projectors
- display walls: tiled projector array

Displays and Devices

- mobile display with laser to retina
- stereo glasses/display
- 3D scanners
  – laser stripe + camera
  – laser time-of-flight
  – cameras only, depth from stereo
- Shape Tape
- haptics (Phantom)
- 3D printers

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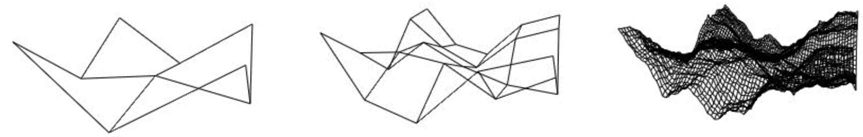
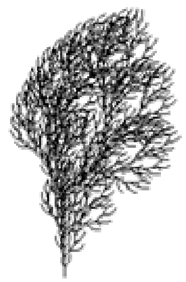
Procedural Approaches

Procedural Approaches

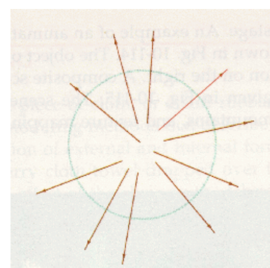
- fractal landscapes



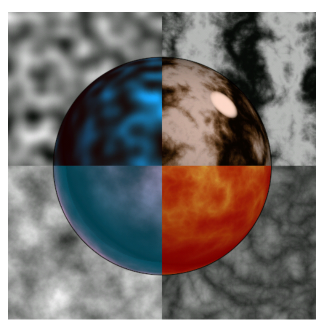
- L-systems



- particle systems



- Perlin noise



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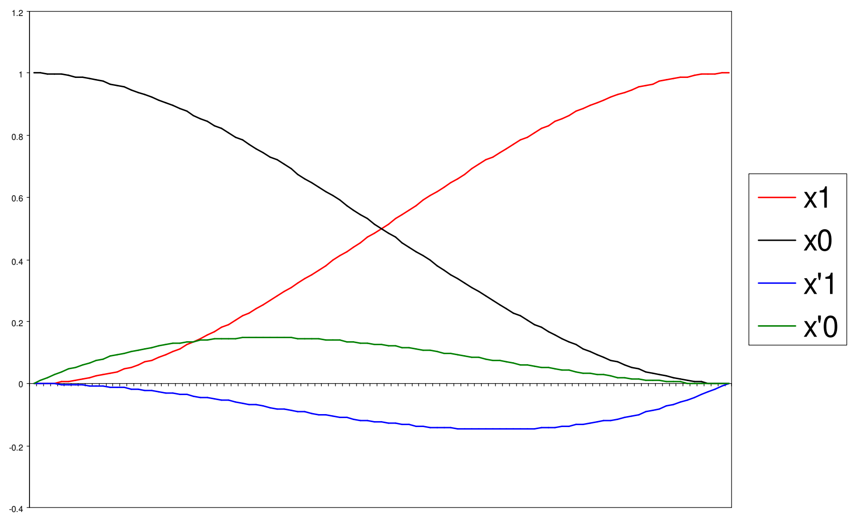
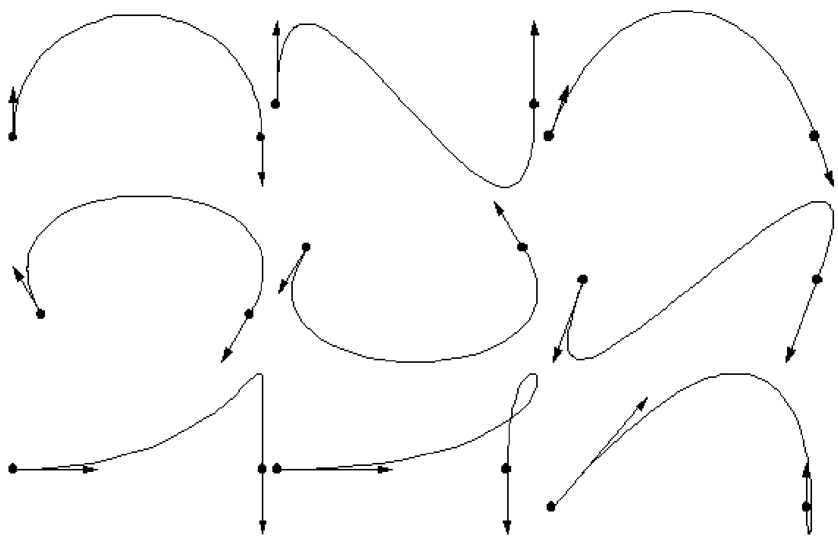
Curves

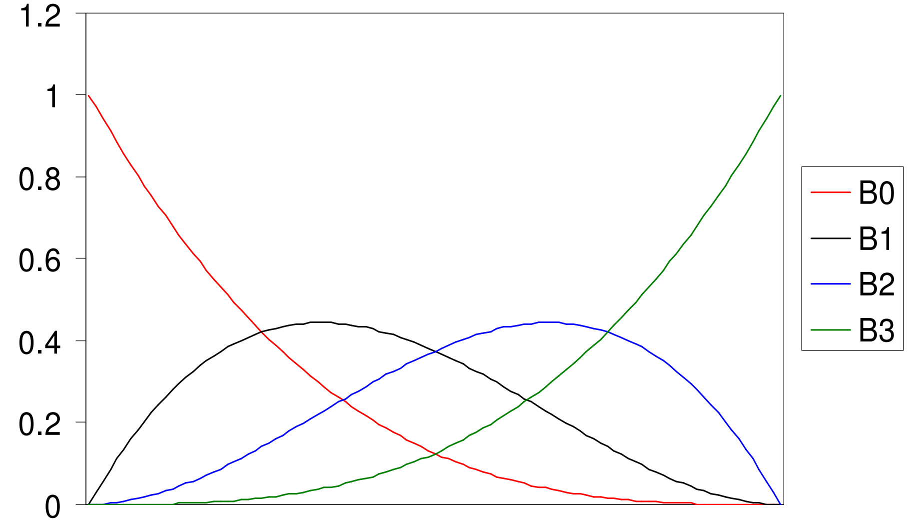
Comparing Hermite and Bezier

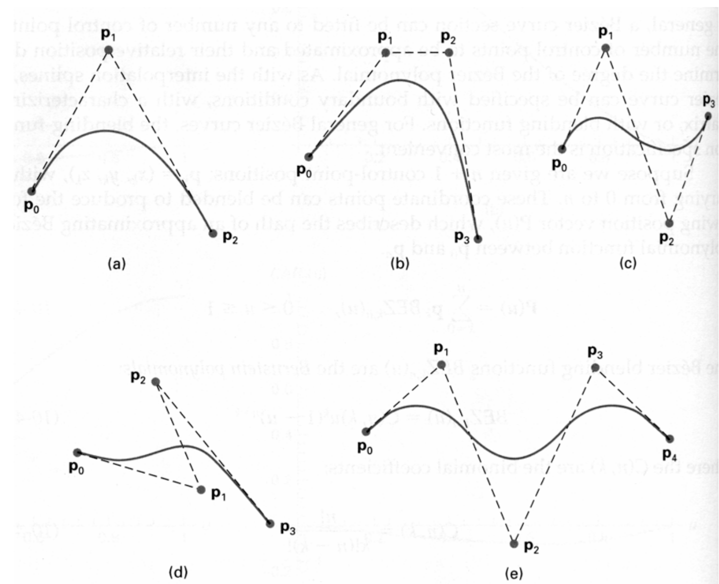
Hermite





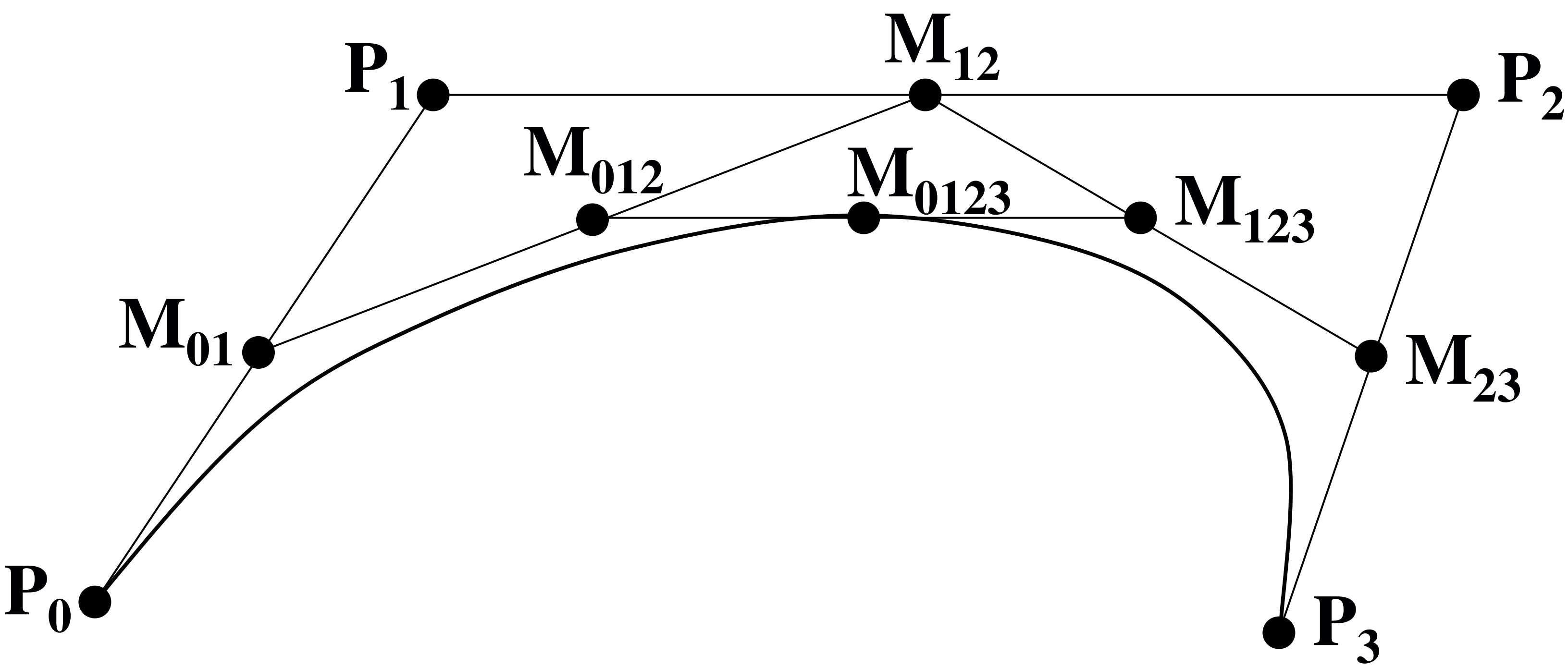
Bezier





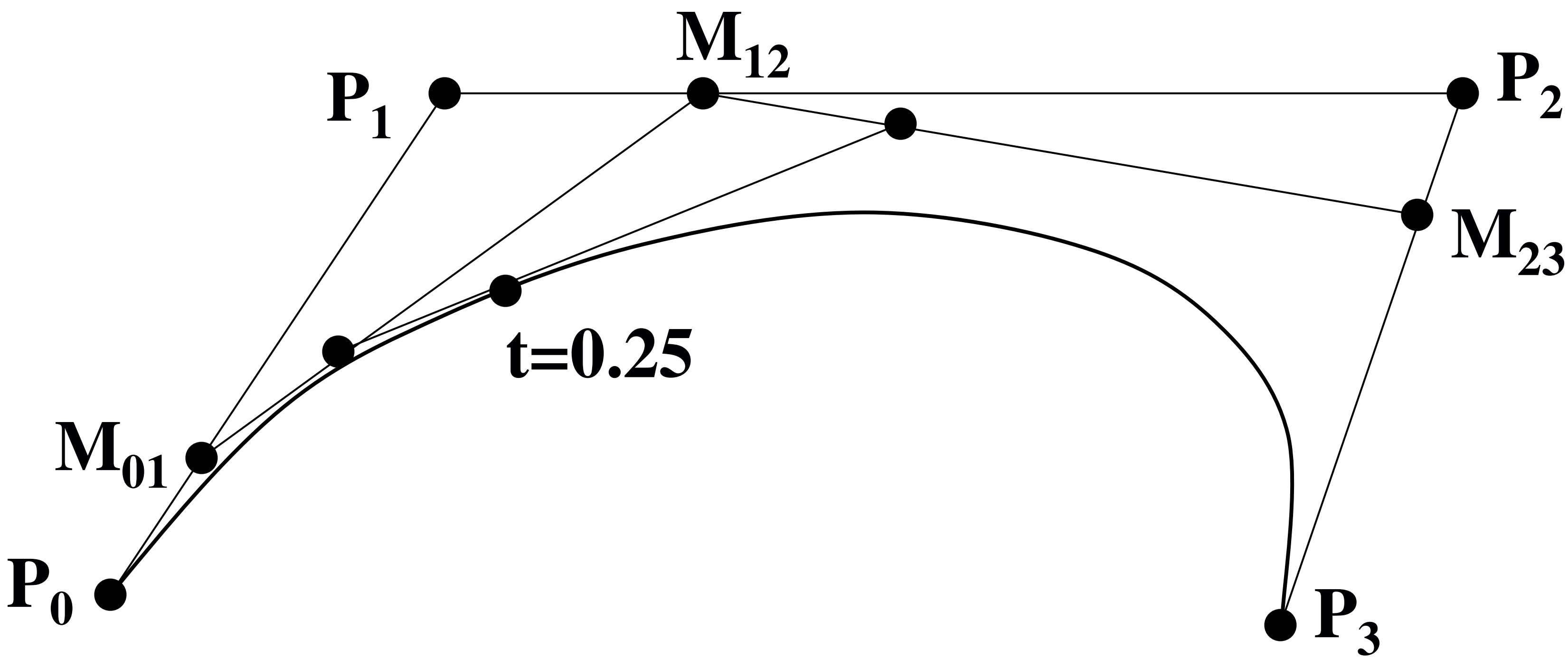
Sub-Dividing Bezier Curves

- step 3: find the midpoint of the line joining M_{012}, M_{123}. call it M_{0123}



de Casteljau's Algorithm

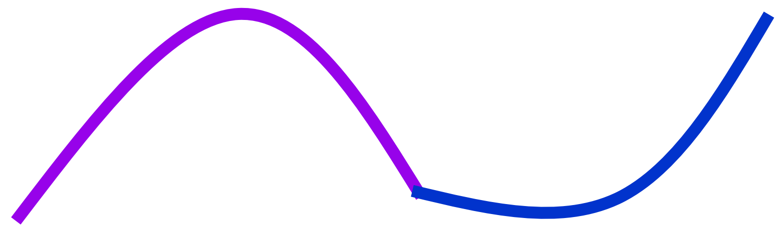
- can find the point on a Bezier curve for any parameter value *t* with similar algorithm
  - for *t=0.25*, instead of taking midpoints take points 0.25 of the way



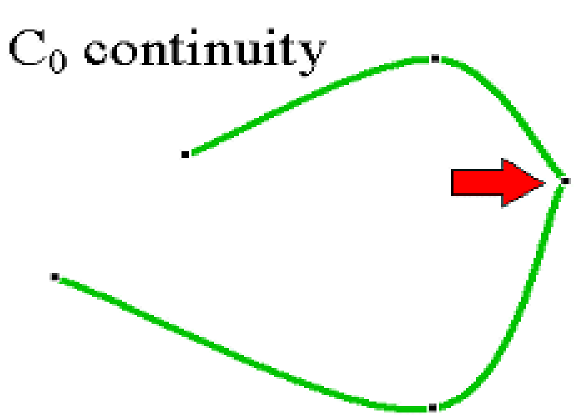
demo: www.saltire.com/applets/advanced_geometry/spline/spline.htm

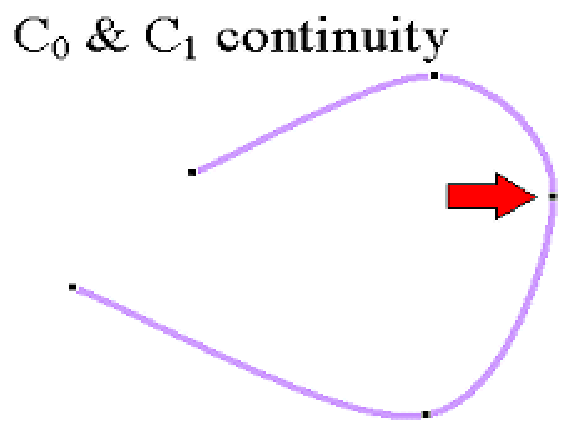
Continuity

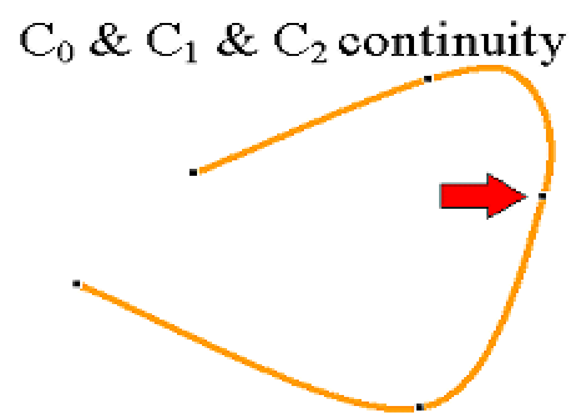
- piecewise Bezier: no continuity guarantees



- continuity definitions
  - C^0: share join point
  - C^1: share continuous derivatives
  - C^2: share continuous second derivatives







B-Spline

- C_0, C_1, and C_2 continuous
- piecewise: locality of control point influence